Update on brain development and the neuroscience of literacy

Martha S. Burns, Ph.D.

March, 2012

The New Science of Learning

- We used to think we were born with brain capacity
  - We inherited it from our parents
  - We did the best we could
  - If a child couldn't learn they were just not smart
- We now know all that is changed

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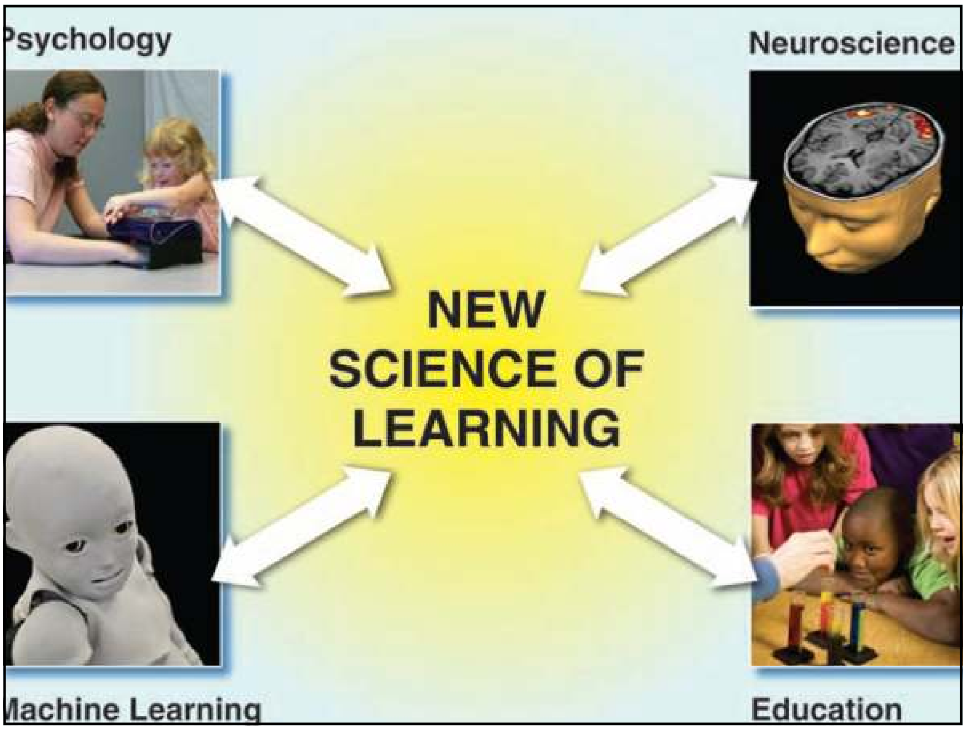
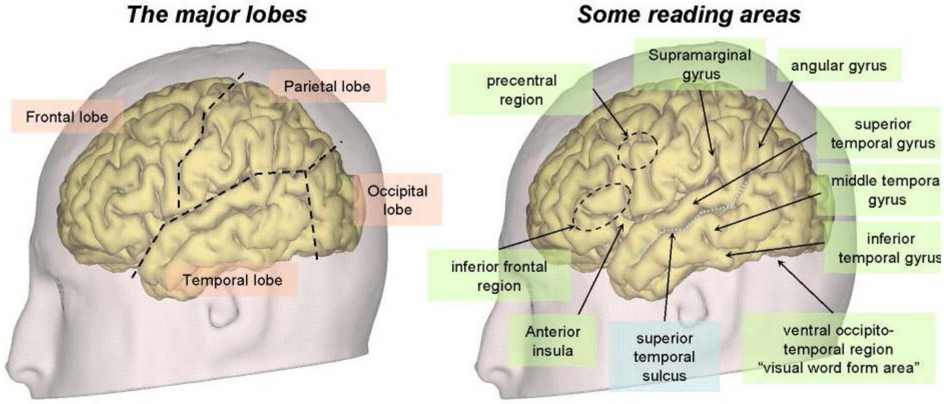
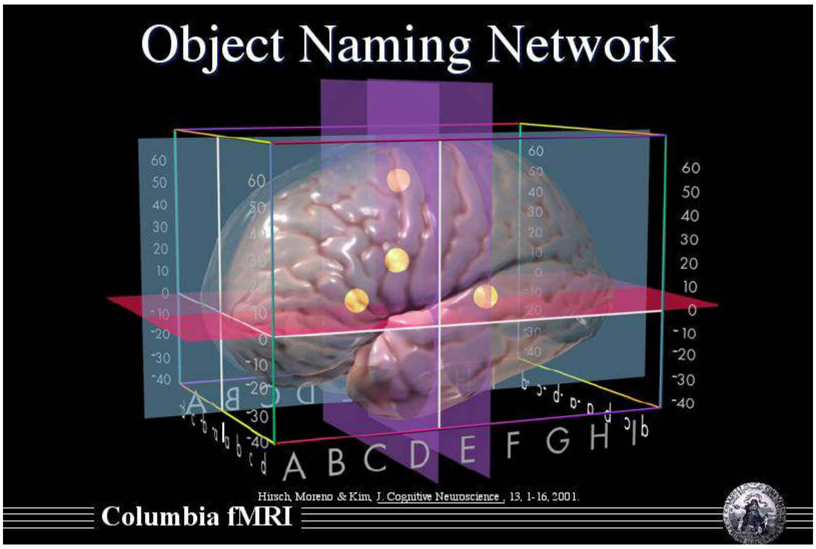




DeHaene, 2009

Neurons that fire together wire together in networks



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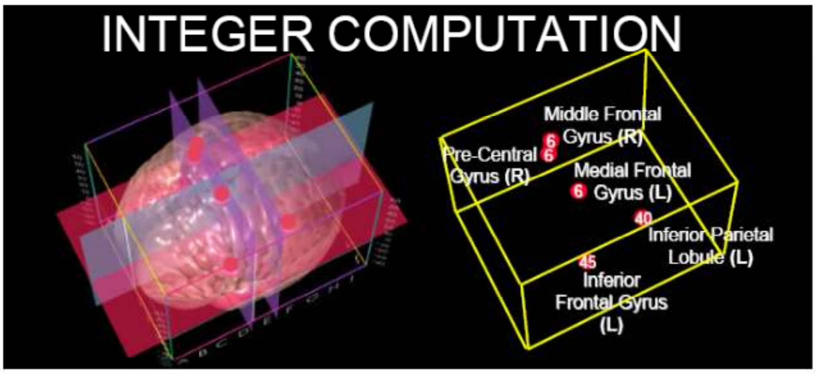

Hirsch, Moreno & Kim, J. Cognitive Neuroscience, 13 (3), 389-405, 2001.

Fig 2c

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The New Science of Language Development

1. What these regions do and…..
   - How they are connected via superhighway system
   - How the highways develop in early years

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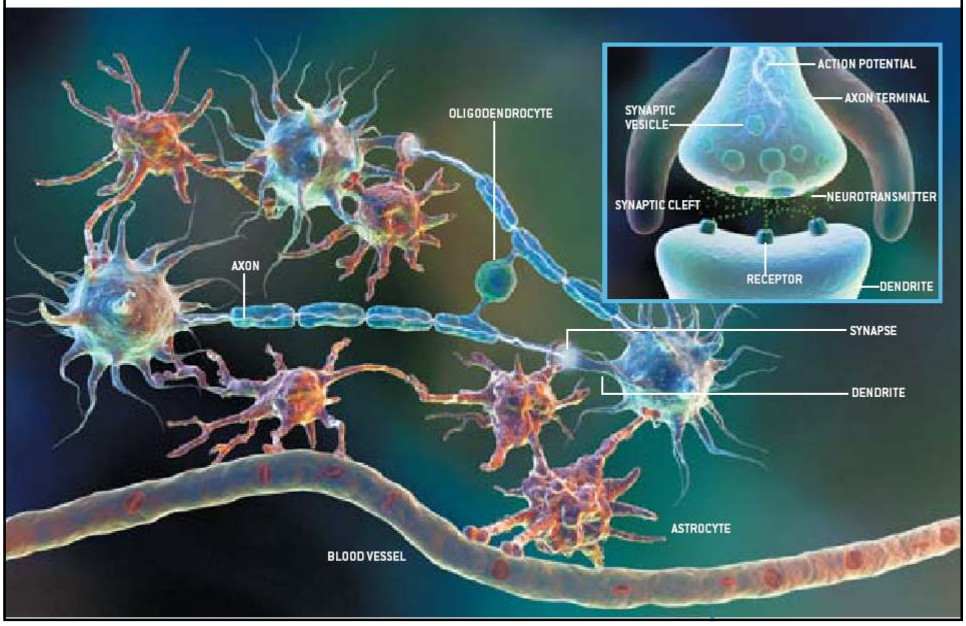
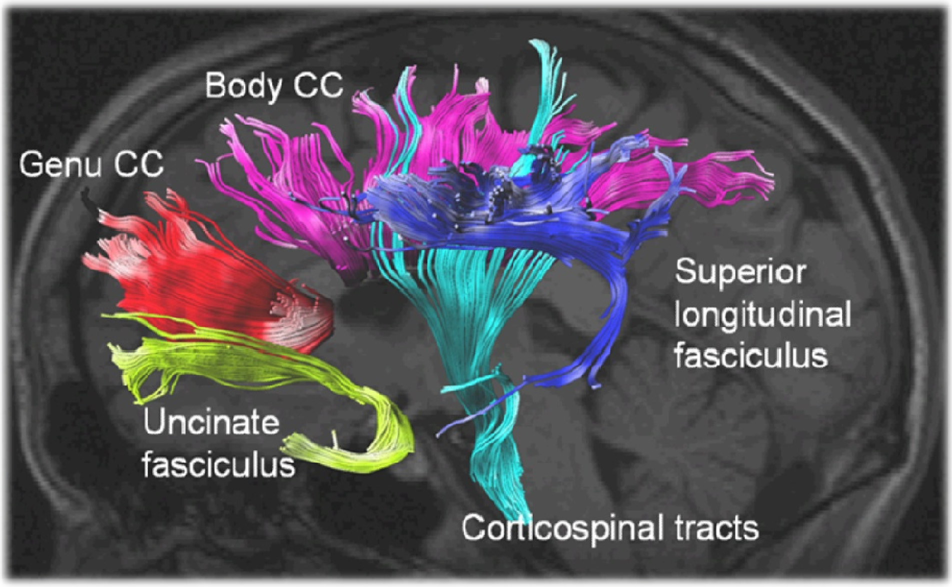
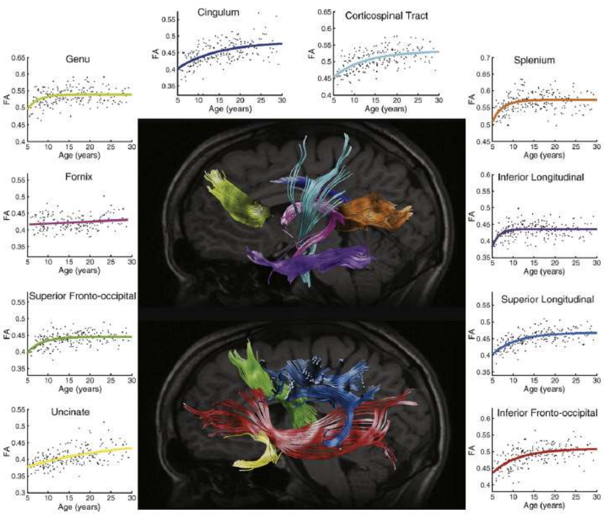
Neuronal Communication System





Tracts mature at different rates



Lebel et al., 2008

How does reading become superimposed on language?

Reading development pyramid --
upper levels depend upon a solid base below

Grade 3+
Grades 1-2
Kindergarten
4 to 5 year old skills
3 to 4 year old development
2 - 3 year old development
Birth to 2 year development

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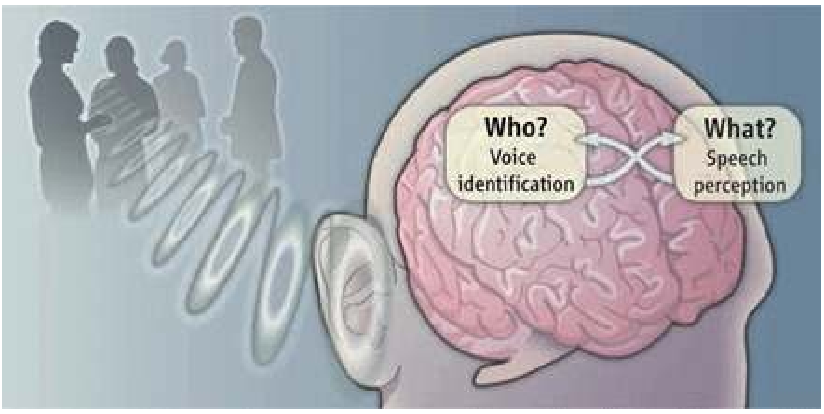
Who? What? A unified sound wave coming from an unseen talker is analyzed to produce two distinct percepts—Who spoke and What was said.

P K Kuhl Science Aug. 19 2011;333:529-530



P K Kuhl Science 2011;333:529-530

Published by AAAS

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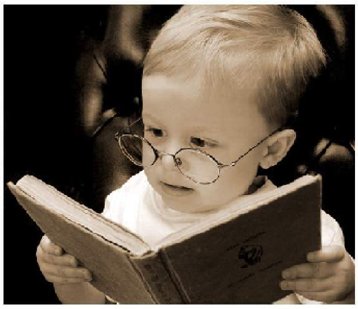
Early Language Development



- The foundation for reading
- The precursor for reading
- For some children, the bottleneck that limits success
- Children differ in language experience

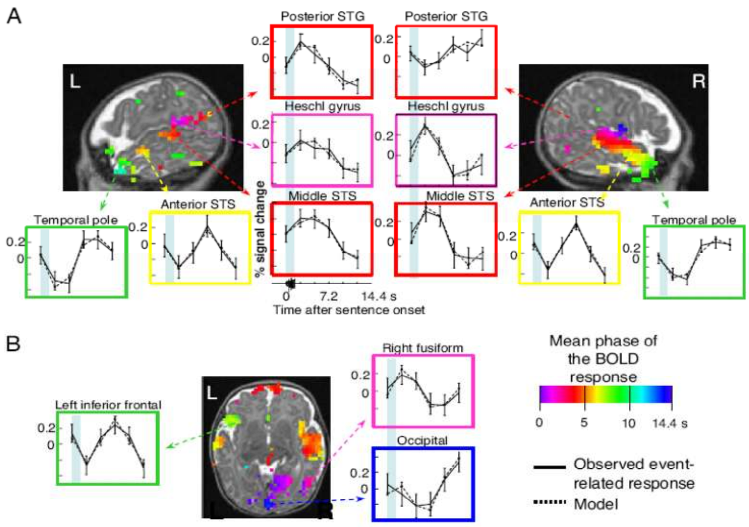
Birth to 2 years

1. Child is born - normal hearing and cognitive potential
2. Makes generalizations about sounds around him/her
   - •speech sounds versus environmental sounds
   - •recognizes speech sounds of own language
3. Uses own language sounds in babbling then early speech
   - •full repertoire of native language phonemes by 18mo.-2 years
   - •early adjectives (good, hot), verbs (see, want, go), pronouns (me,you)

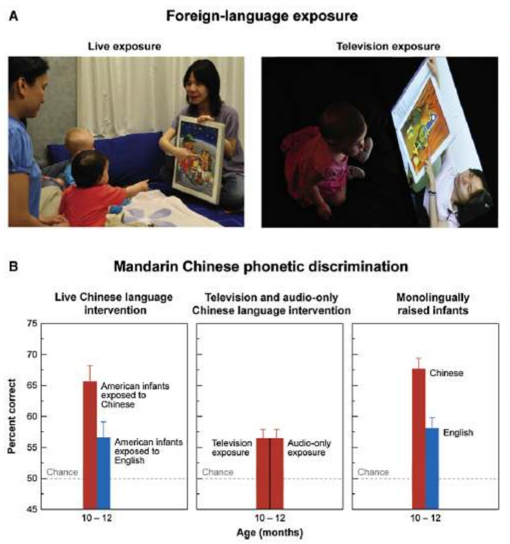
10-12 months - first word

18 months - 10-20 words; 2 yr.- two word phrases; 200 words

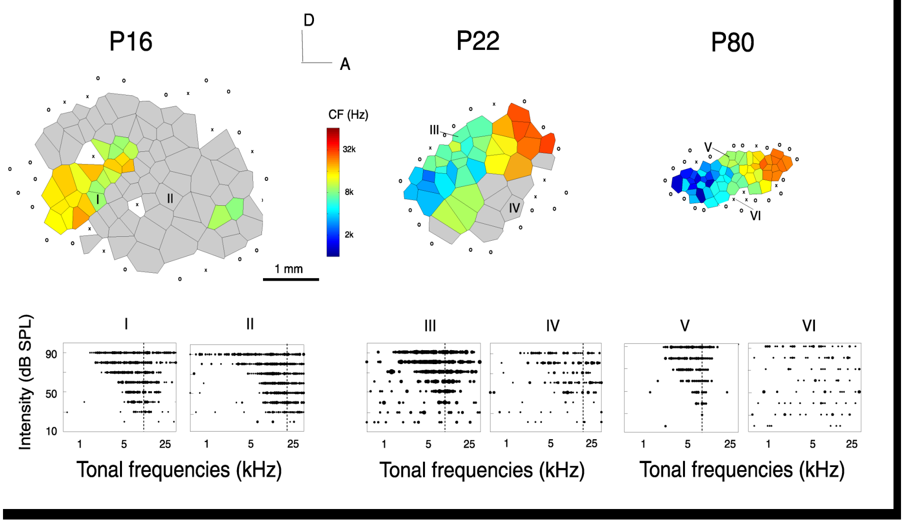
Organization of cortical responses to spoken language in 3 m old infants.



Dehaene-Lambertz, et. al, 2006



Normal Development of the Brain Maps for Hearing



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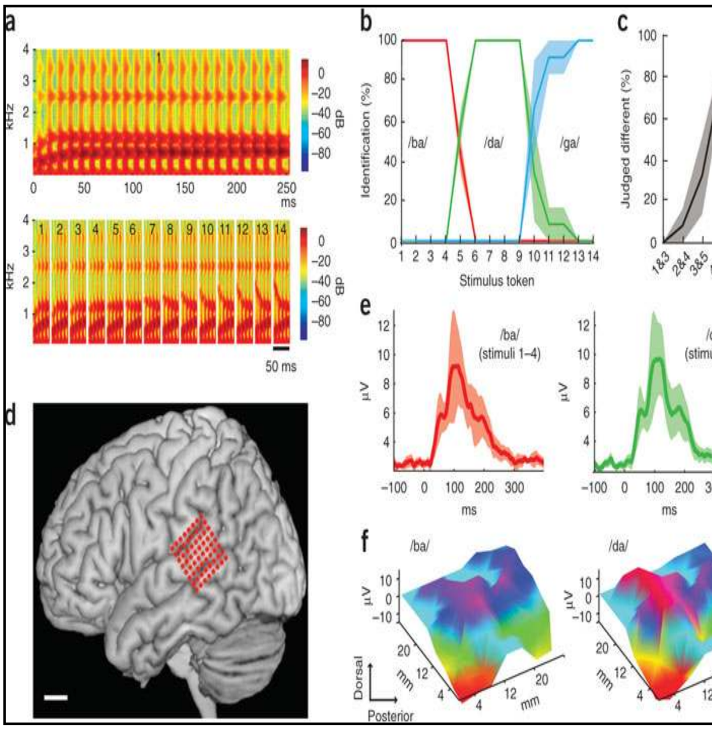
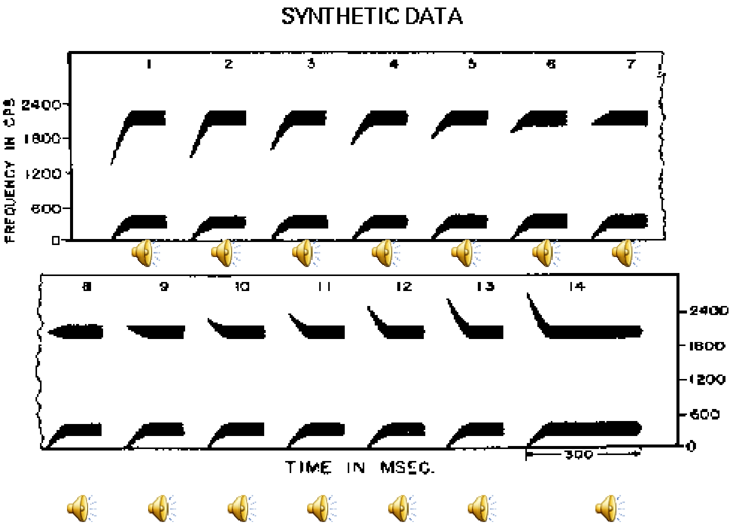
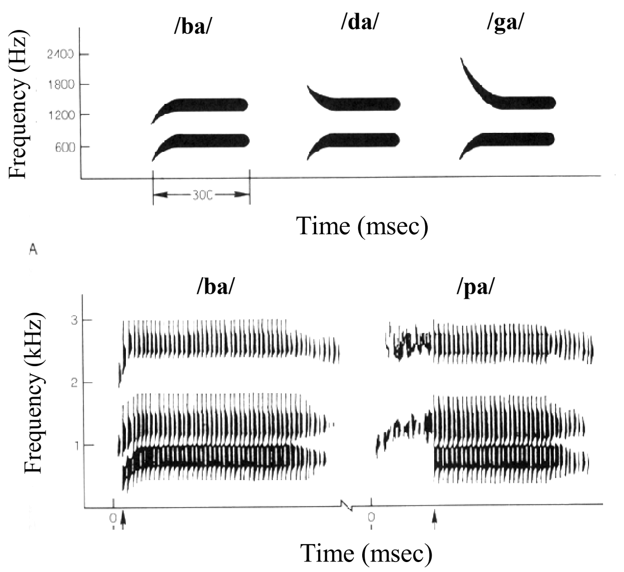
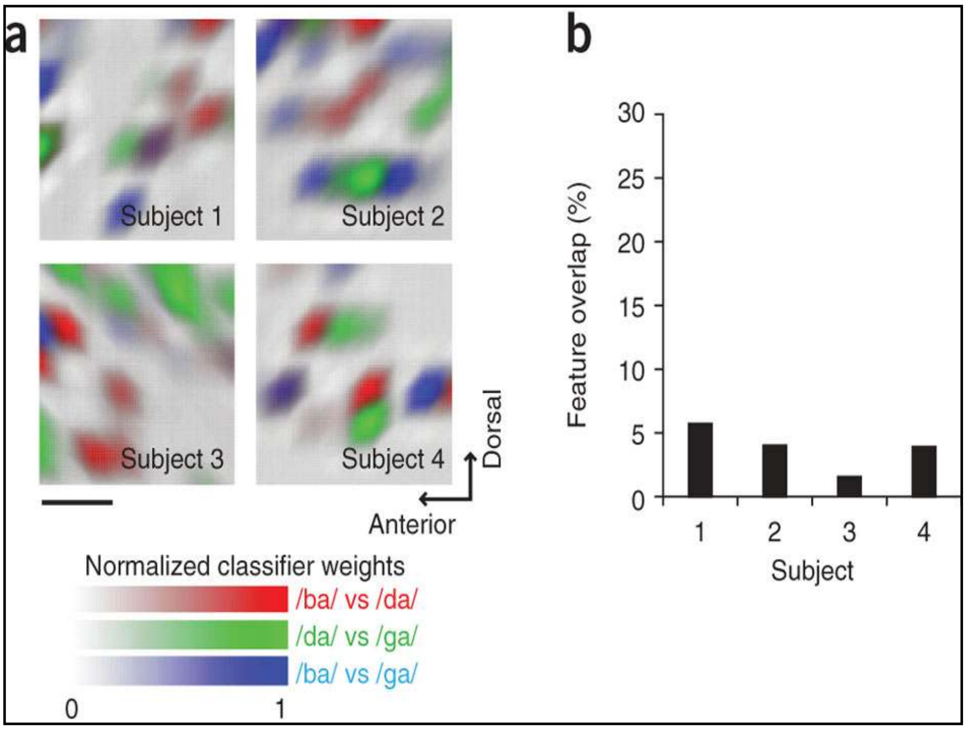


Chang, et al, 2010

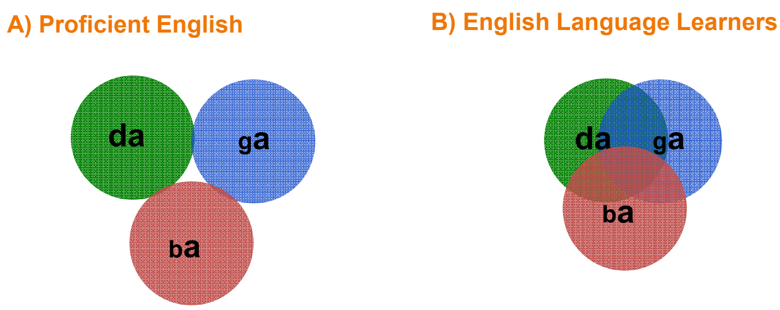
Categorical Perception







English Phonemic Cortical Representation

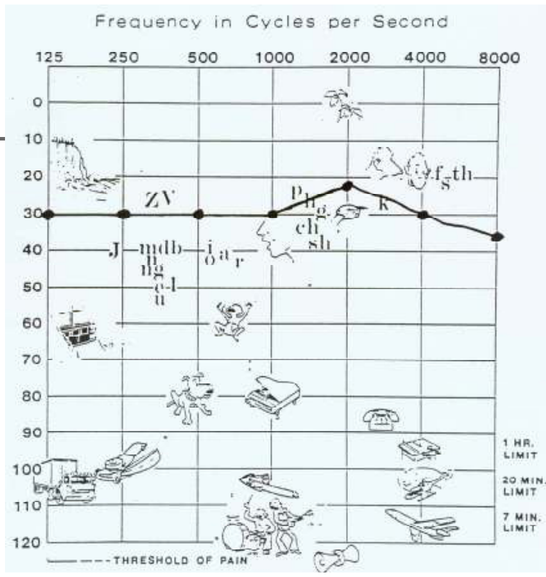


Infants exposed to TV or audio only show no difference in acquisition of the new sound system compared with children never exposed. Infants exposed through social interaction of the same duration and intensity acquire the new phonology.

A

BUT AFTER THE CRITICAL PERIOD DIRECT INSTRUCTION IS NECESSARY

23



Brain maps depend on hearing the sounds

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Two to three years-early phonological awareness

1. Word play - “Higglety, pigglety, pop”; “Hickory, Dickory, Dock”
2. Rhymes and alliterative stories
   - •Little Miss Muffett
     Sat on a tuffett
   - •Peter piper picked a peck of pickled peppers
3. Delayed expressive syntax and phonology predict poor reading three years later

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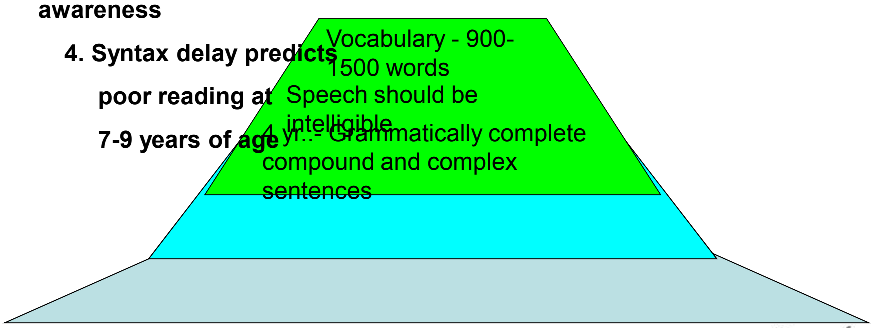
Three to four years

1. 91% can recognize incorrect productions of words they know

2. 27% can be enticed to do sound play; 25% can rhyme

3. Poor speech discrimination will lead to poor phonological awareness

4. Syntax delay predicts poor reading at 7-9 years of age



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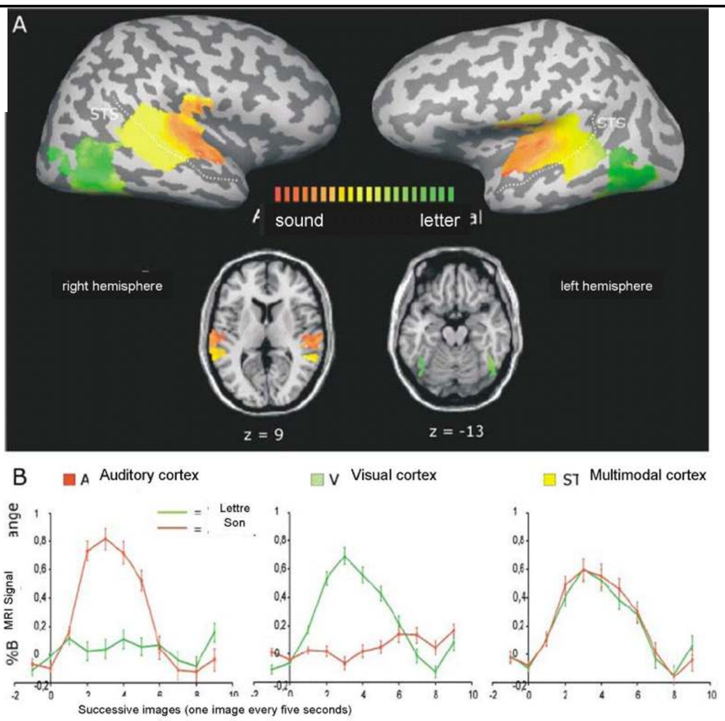

PNAS

Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset

Nora Maria Raschle[a,b], Jennifer Zuk[a], and Nadine Gaab[a,b,c,1]

[a]Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Department of Medicine, Children's Hospital Boston, and [b]Harvard Medical School, Boston, MA 02115; and [c]Harvard Graduate School of Education, Cambridge, MA 02138

Edited by Michael Merzenich, W. M. Keck Center for Integrative Neuroscience, University of California, San Francisco, CA, and approved December 8, 2011 (received for review May 17, 2011)

Individuals with developmental dyslexia (DD) show a disruption in posterior left-hemispheric neural networks during phonological processing. Additionally, compensatory mechanisms in children and adults with DD have been located within frontal brain areas. However, it remains unclear when and how differences in posterior left-hemispheric networks manifest and whether compensatory mechanisms have already started to develop in the prereading brain. Here we investigate functional networks during phonological processing in 36 prereading children with a familial risk for DD (n = 18, average age = 66.50 mo) compared with age and IQ-matched controls (n = 18; average age = 65.61 mo). Functional neuroimaging results reveal reduced activation in prereading children with a family-history of DD (FHD⁺), compared with those without (FHD⁻), in bilateral occipitotemporal and left temporoparietal brain regions. This finding corresponds to previously identified hypoactivations in left hemispheric posterior brain regions for school-aged children and adults with a diagnosis of DD. Furthermore, left occipitotemporal and temporoparietal brain activity correlates positively with prereading skills in both groups. Our results suggest that differences in neural correlates of phonological processing in individuals with DD are not a result of reading failure, but are present before literacy acquisition starts. Additionally, no hyperactivation in frontal brain regions was observed, suggesting that compensatory mechanisms for reading failure are not yet present. Future longitudinal studies are needed to determine whether the identified differences may serve as neural premarkers for the early identification of children at risk for DD.

functional MRI | pediatric neuroimaging | reading disability | developmental disorder | learning disability

Developmental dyslexia (DD) is a specific learning disability that affects about 5–17% of all children (1, 2). DD is characterized by difficulties with accurate and fluent word recognition and poor spelling and decoding performance. DD cannot be accounted for by poor vision, hearing, or a lack of motivation. Molecular-genetic, twin, and family studies have shown a marked familial risk for DD, with an increasing prevalence in families with one or more members with a diagnosis of DD or reading difficulties (e.g., refs. 3 and 4). In addition, several DD susceptibility genes crucial for early brain development have been reported (5–8). DD can have severe social and psychological consequences (9–11) and may impact a child's life beyond their academic pursuits. Studies have shown that children with learning disabilities are less likely to complete high school (12) and are more likely to enter the juvenile justice system (13).

Most researchers, clinicians, and reading specialists agree that DD typically results from a weakness in the ability to manipulate oral speech sounds of language (2, 14). Individuals with DD are often unable to access the underlying sound structures of words, creating a difficulty in mapping sounds to written language (15–18). Phonological processing skills have been found to be a key predictor of later reading ability in preschool and elementary school-aged children (19–31). In addition to phonological processing deficits, a range of other linguistic impairments have been observed in infants and prereading children who later exhibit weak reading scores, including speech perception (23, 26), syntax production, and comprehension (32–35), language comprehension (26), receptive vocabulary (22, 34), and rapid automatized naming abilities (23, 24, 34, 36–38).

With the advent of modern neuroimaging tools, it is now possible to study the neural substrates of reading and reading-related processes in the conscious human brain. Functional MRI (fMRI) studies have revealed a characteristic network of posterior brain areas typically involved in reading and reading-related tasks in children and adults including: (i) the dorsal or temporoparietal circuit (including lateral extrastriate and left inferior occipital areas) and (ii) the ventral or occipitotemporal circuit [including angular and supramarginal gyrus, inferior parietal lobe, and posterior aspects of the superior temporal gyrus (39–43)]. Cross-sectional studies have demonstrated changes in these highly integrated reading networks depending on reading skill level (e.g., refs. 44 and 45) and converging evidence points toward a characteristic hypoactivation of temporoparietal as well as occipitotemporal brain areas in individuals with DD (44, 46–55).

These functional characteristics in posterior brain regions in children and adults with DD have been complemented by anatomical abnormalities. Voxel-based morphometry reveals differences in gray-matter volume indices in individuals with DD (compared with typical reading controls) in various areas of the brain, including left occipitotemporal and temporoparietal areas (44, 56–61), bilateral fusiform (59), and lingual gyrus (LG) (58) as well as the cerebellum (56–58). Morphological abnormalities in these regions can be identified even before reading skills are present in children as young as 5 to 6 y of age, suggesting atypical early development or even a genetic basis for DD (62).

Furthermore, an increase in activation in left frontal and right lateralized anterior brain areas has been shown in individuals with DD (44, 45, 49, 50, 63). This hyperactivation seen in individuals with DD has been suggested to reflect a compensatory mechanism for the dysfunctional reading system (e.g., refs. 44, 50, and 64). Furthermore, it has been shown that right prefrontal activation in children with a diagnosis of DD can significantly predict reading gains 2.5-y later, indicating that these compensatory mechanisms can function as part of the reading network (64).

Although there is converging evidence suggesting a characteristic structural and functional phenotype of DD, the mechanism

Author contributions: N.M.R. and N.G. designed research; N.M.R. and J.Z. performed research; N.M.R., J.Z., and N.G. analyzed data; and N.M.R., J.Z., and N.G. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

[1]To whom correspondence should be addressed. E-mail: nadine.gaab@childrens.harvard.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1107721109/-/DCSupplemental.

2156–2161 | PNAS | February 7, 2012 | vol. 109 | no. 6

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Raschle et al., PNAS Feb. 7, 2012

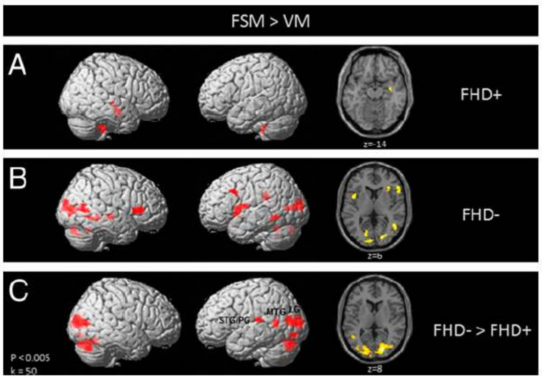
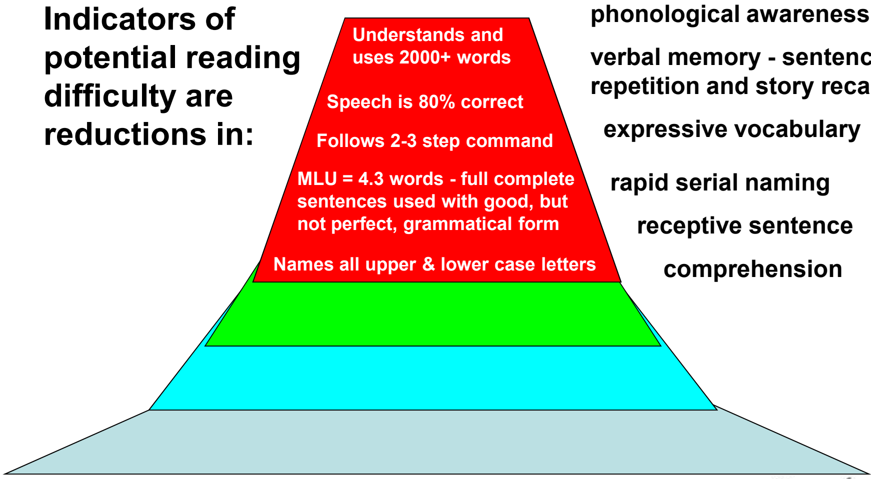


Fig. 1. Statistical parametric maps showing brain activation during phonological processing (FSM > VM) for children with (*A*) and without (*B*) a familial risk for DD, as well as group differences between children with compared to without ($FHD^- > FHD^+$) a familial risk for DD (*C*). FHD^- show significantly greater activation compared to FHD^+ children in bilateral occipitotemporal and left temporoparietal brain regions, as well as left and right cerebellar regions.

Kindergarten

Indicators of potential reading difficulty are reductions in:



phonological awareness

verbal memory - sentence repetition and story recall

expressive vocabulary

rapid serial naming

receptive sentence comprehension

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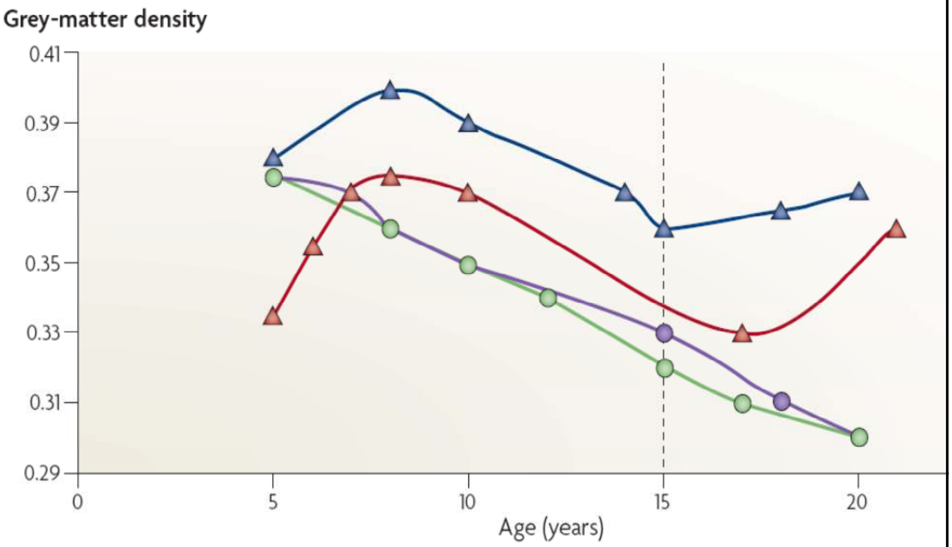
Plots of grey-matter density are based on data by Gogtay *et al.* 2004 and illustrate the local grey-matter density in the mid-dorsolateral prefrontal cortex in red, in the angular gyrus of the parietal cortex in blue, in the posterior superior temporal sulcus of the temporal cortex in purple, and in the occipital pole in green.



Second Language Learning

- Affects the way the brain is organized for language
- Differs depending upon when the second language is learned
- After the critical period requires the same developmental criteria as the first language

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ELL

- Need to build the ability to perceive internal detail to words
- Phonics instruction is a much less transparent in English than many other languages
  - Much easier to learn to read Spanish than English (DeHaene, 2009)

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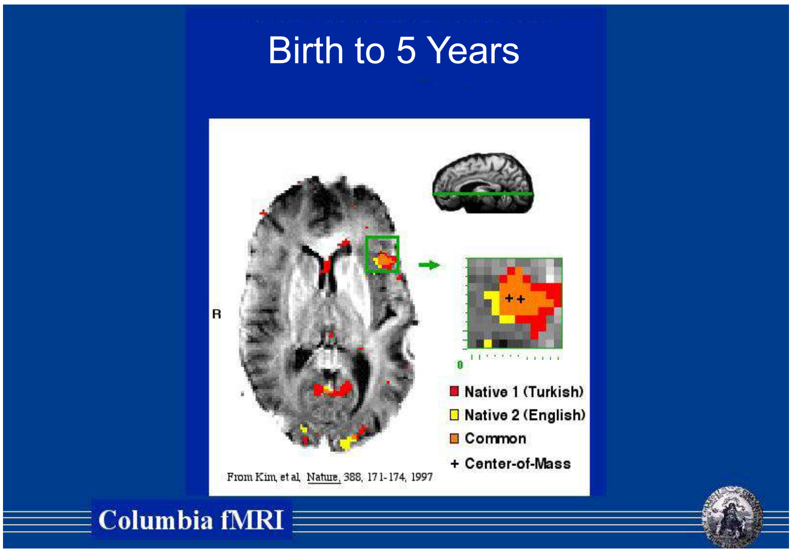
Learning a Second Language During Critical Period



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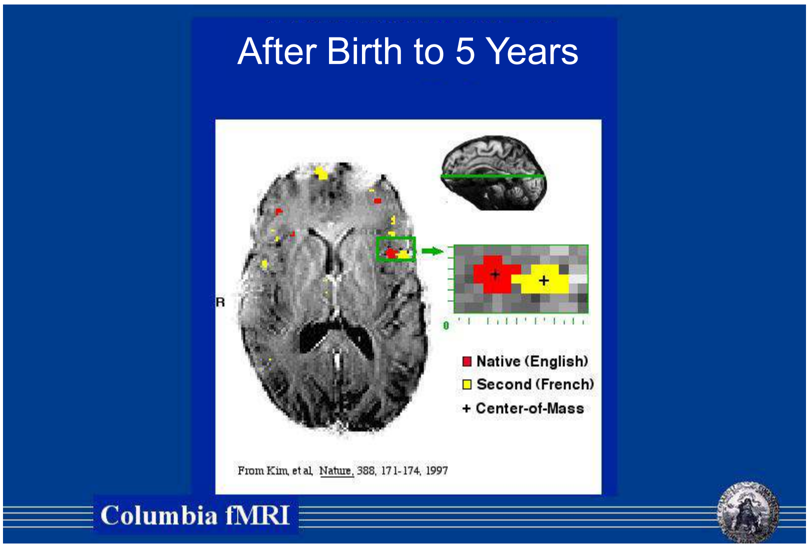
Learning a Second Language After Critical Period



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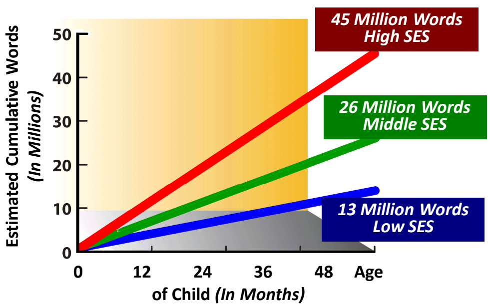
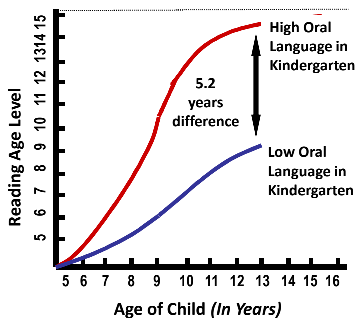
Language Exposure and SES

Cumulative Effects of Language Experience



(Hart and Risley, 1995)

Effects of Low Language Development on Reading



(Loban, 1967; Hirsch, 1996)

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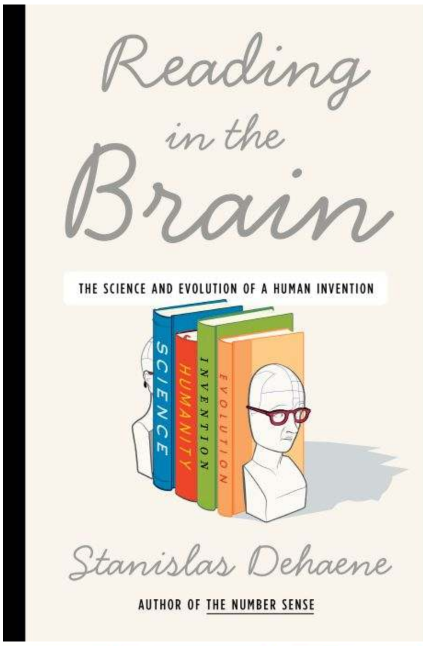

So what about reading?

Viking Press

December 2009

“The Reading Paradox” Dehaene, 2009

- Human brains evolved over millions of years without writing – reading is 5000 years old
  - No special brain regions evolved for reading
- Humans read because we can link visual elements to speech sounds and meanings.
  - recycles existing brain circuitry
  - results in a large-scale ‘neuronal workspace’ that
    - assembles,
    - confronts,
    - recombines, and
    - synthesizes knowledge

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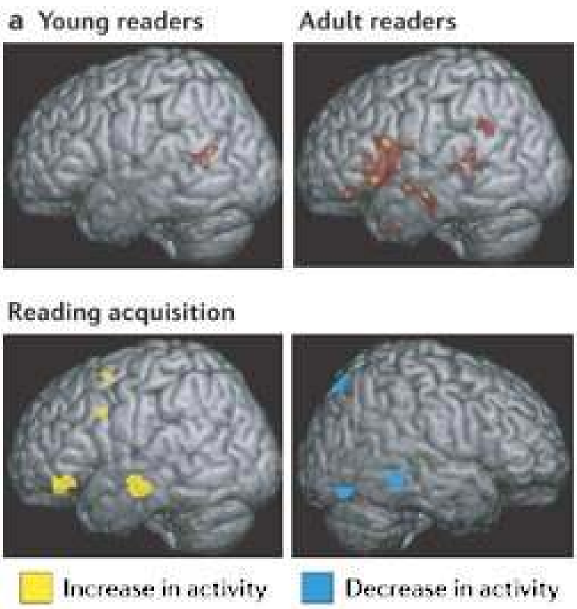

Turkeltaub et al *Nature Neuroscience* 2003

nature REVIEWS NEUROSCIENCE

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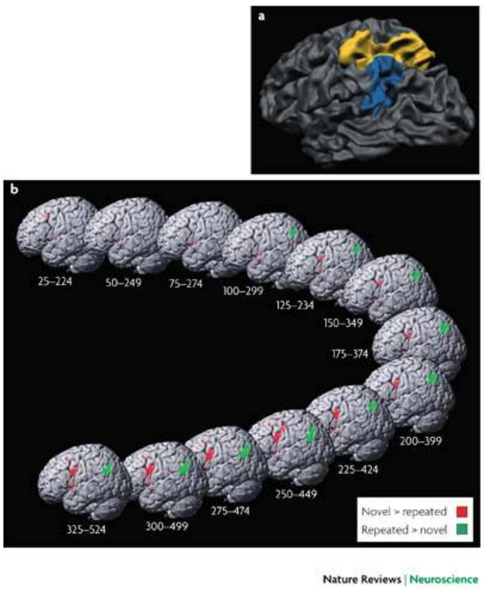

a | Training for arithmetic problems leads to decreasing engagement of the inferior parietal cortex (shown in yellow) and increasing recruitment of the angular gyrus (shown in blue).

b | a moving time window of 200 scans and reveals that there are significant changes in activity of the angular gyrus (shown in green) after only approximately 8 repetitions of a problem

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How Learning to Read Changes the Cortical Networks for Vision and Language
"The Reading Paradox"

Science ***330, 1359 (2010);***
Stanislas Dehaene*, et al.*

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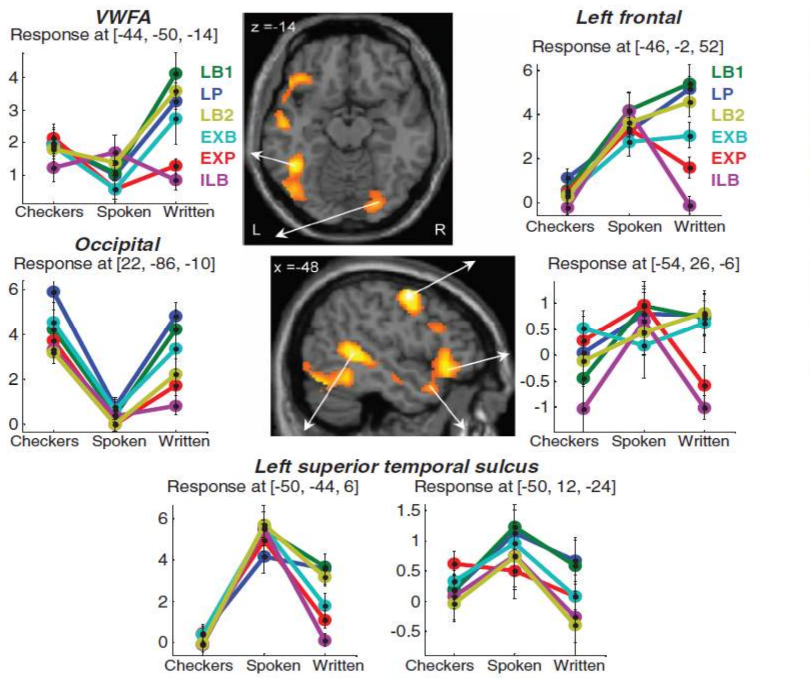


Literacy Enhances Brain Responses in Three Ways (DeHaene, 2010)

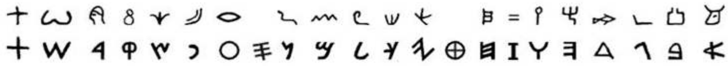
- Boosts organization of the visual cortex
- Allows practically the entire left hemisphere spoken language network to be activated by written sentences
- Refines spoken language processing by enhancing the phonological region

Written Expression

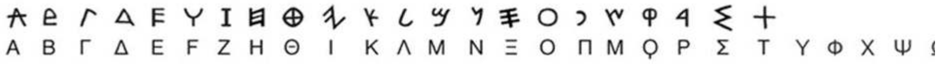
- Handwriting
- Spelling
- Written formulation

The logic of alphabetic systems

From proto-Sinaitic to Phoenician: hieroglyphs give way to a limited set of letters

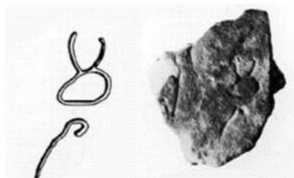


From Phoenician to Greek: letter rotation and emergence of vowels



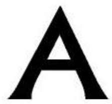
Lascaux

Proto-Sinaitic



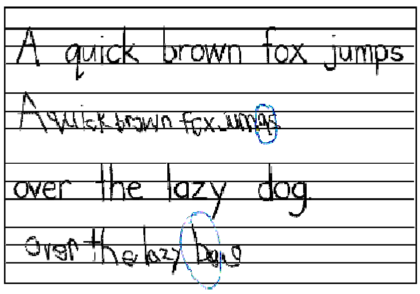
Phoenician

Greek / Latin

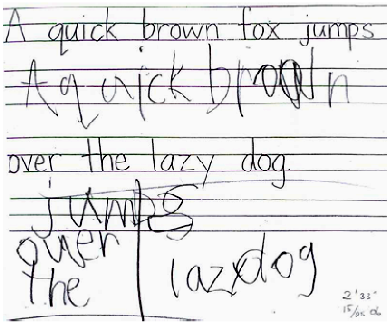


(middle) adopted a small set of conventional pictures to represent the consonants of Semitic language. During their adoption by the Phoenicians and the Greeks, these shapes were further simplified and rotated by 90 or 180 degrees, under the influence of changes in the direction of writing. They ultimately became the letters of our alphabet. Each of them, such as the letter A (bottom), can be seen as the end point of a cultural evolution that tended toward greater simplicity while maintaining a core shape that could be recognized easily by our inferior temporal neurons.

Writing requires the “letter box”



It also requires visuo-spatial organization



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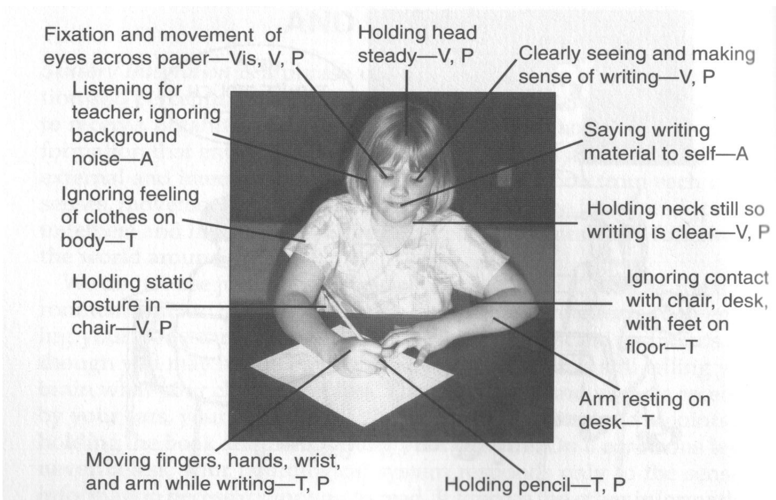
Sensory-Motor Brain Pillar



BrainFit Studio

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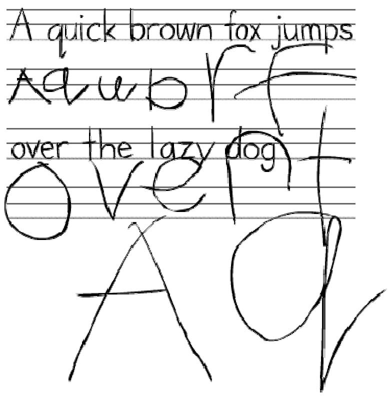
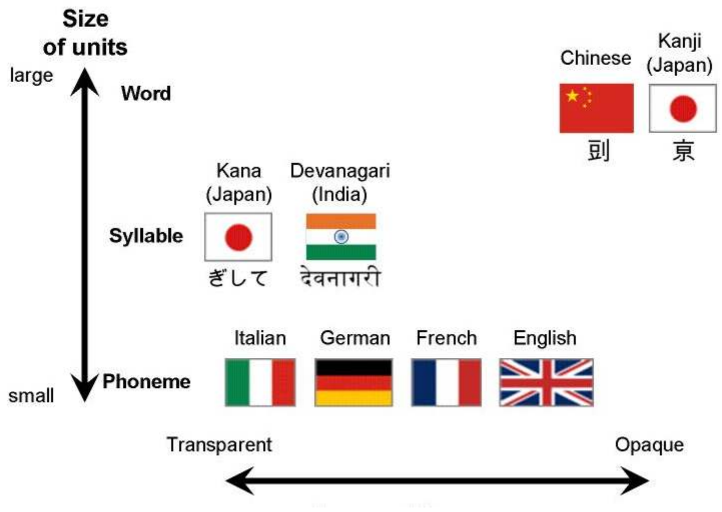
And it requires working memory and fine motor control

- Praxis (fine motor skills)



Spelling

- English is a non-transparent language
  - There are many alternate spellings for the same sounds
    - George Bernard Shaw said we could spell “fish” as phoeti
      - - ‘f’ sound as ph as in “phone”
      - ‘I’ sound as oe as in “Phoebe”
      - ‘sh’ sound as ti in “Nation”



Spelling

- Often makes no sense
- Requires good phonic skills to start
- Requires learning many spelling rules
- And it also requires excellent visual working memory
  - How many of you check spelling by looking at your word written out

Understanding the brain science of students who struggle to read

Martha S. Burns, Ph.D.

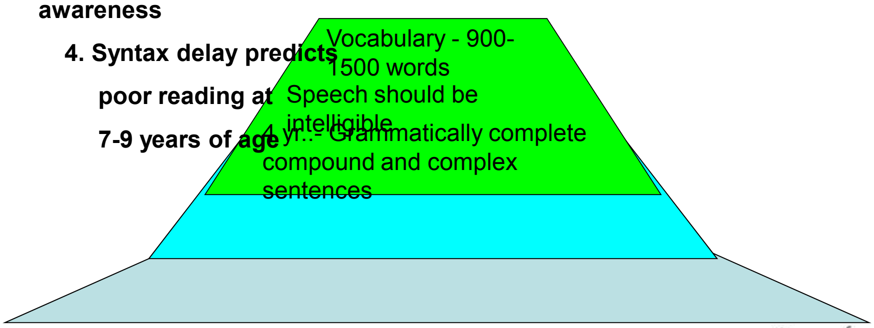
March, 2012

What we know about struggling learners

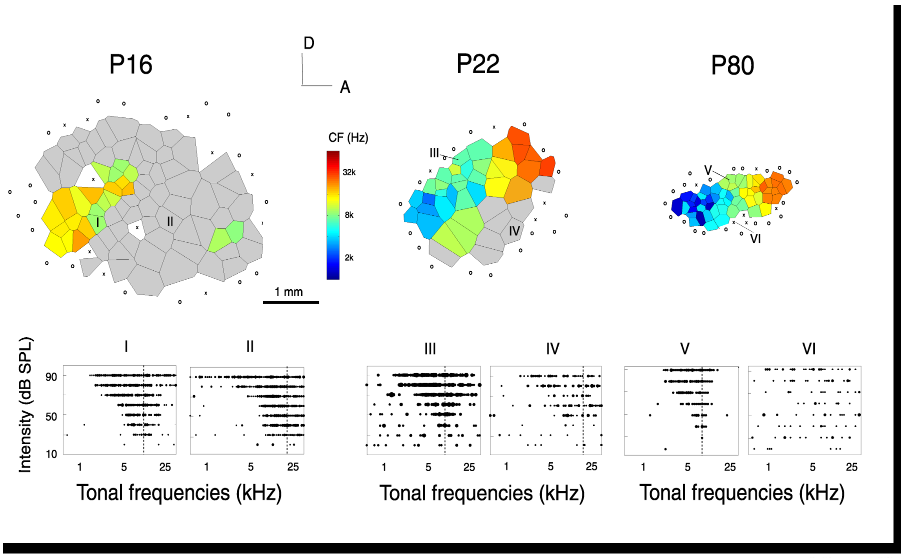
- The vast majority of struggling learners are experiencing problems with reading and/or executive functions

Three to four years

1. 91% can recognize incorrect productions of words they know
2. 27% can be enticed to do sound play; 25% can rhyme
3. Poor speech discrimination will lead to poor phonological awareness
4. Syntax delay predicts poor reading at 7-9 years of age



Normal A1 development



Zhang, Bao & Merzenich, Nature Neuroscience, 2001

Four ways to degrade sensory cortex (aural language and somatosensory cortex) development

- structured noise **Zhang et al (2004) PNAS**
- continuous, unmodulated noise **Chang et al (2003) Nature Neurosci; Chang et al (2005) PNAS**
- perinatal anoxia **Strata et al (2005) PNAS**
- non-coplanar PCBs (PBDEs?) **Kenet et al (2006) submitted, Nature Medicine**

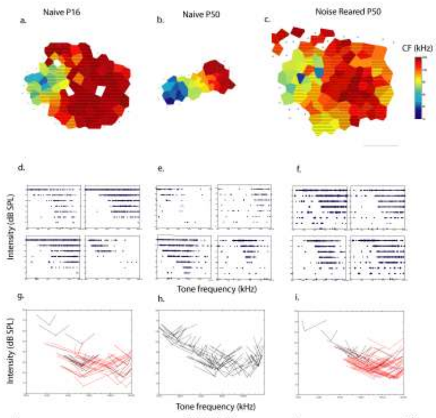
Scientific Learning®

A1 does not mature in infants raised in continuous noise

- In continuous noise reared rats, the critical period remains open indefinitely

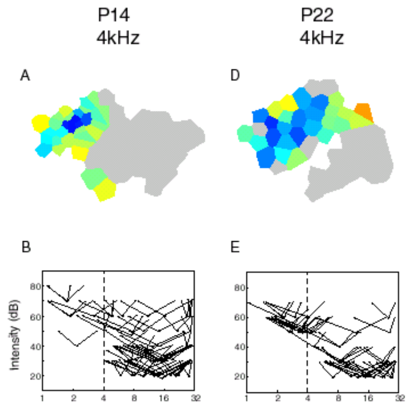
Scientific Learning®

A1 does NOT mature in rats raised in CONTINUOUS noise.



Chang et al. (2003) ms submitted for publication

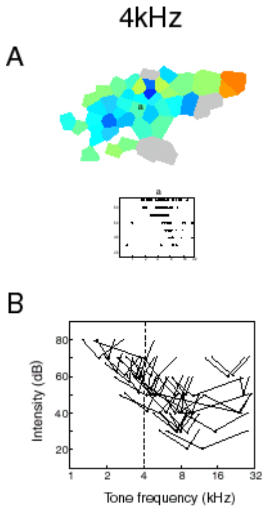
A1 processing is "specialized" as the infant rat is exposed to specific sound stimuli



A learning context is NOT required --- as it is after the end of the critical period.

Zhang, Bao & Merzenich, Nature Neuroscience, 2001

Perinatally generated representational distortions in A1 tonotopy and input selectivity persist into adulthood.

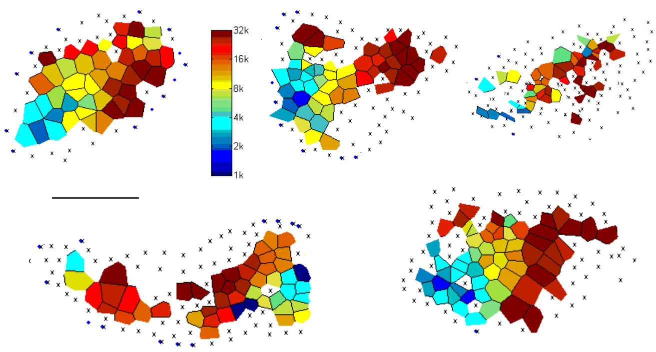


Zhang, Bao & Merzenich, Nature Neuroscience, 2001

PCB poisoning radically alters cortical map development

Normal

PCB exposed animals



Exactly the same bizarre typography seen in autism

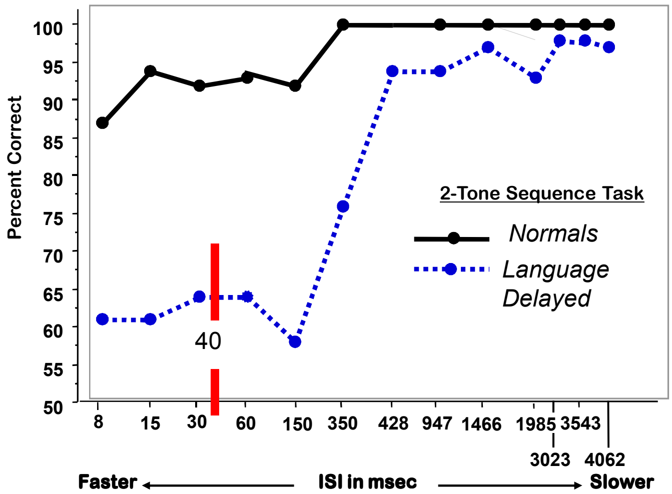
PCB exposure in pregnant mothers .87 correlation with % of autism – some regions of Texas – Merzenich, 2006

APD – Language and Reading

Processing Speech

- Students need to distinguish speech sounds correctly so they can learn the rules of language and associate sounds with letters
- Speech sounds can differ by as little as 10 milliseconds
- Computers can emphasize the differences in sounds to make them easier to distinguish

Faster Auditory Processing

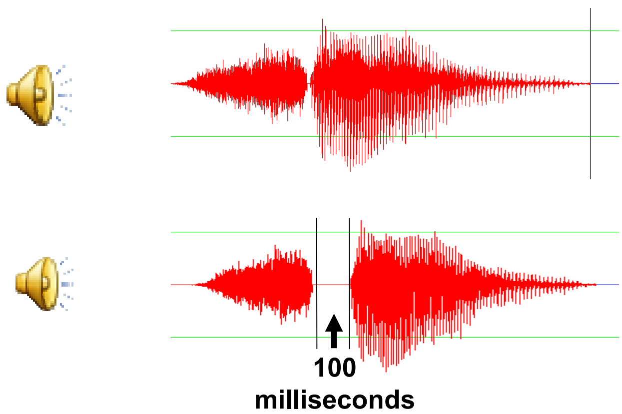


Tallal, P & Piercy, M (1973) Nature, 241

Scientific Learning

Small Changes in Timing

. . .Big Changes in Meaning



Scientific Learning

Auditory processing disorders in children with ASD (Russo, et al, 2009)

- *Journal of Autism and Developmental Disorders* Volume 39, Number 8, 1185-1196, 2009
- Provides new evidence of deficient auditory cortical processing of speech in noise in autism spectrum disorders (ASD).
  - Speech-evoked responses (~100–300 ms) in quiet and background noise were evaluated in typically-developing (TD) children and children with ASD.
  - ASD responses showed delayed timing (both conditions) and reduced amplitudes (quiet) compared to TD responses.
  - As expected, TD responses in noise were delayed and reduced compared to quiet responses. However, minimal quiet-to-noise response differences were found in children with ASD, presumably because quiet responses were already severely degraded.
  - Moreover, ASD quiet responses resembled TD noise responses, implying that children with ASD process speech in quiet only as well as TD children do in background noise.

Scientific Learning®

Neu
Artic

Altered Low-Gamma Sampling in Auditory Cortex Accounts for the Three Main Facets of Dyslexia

Katia Lehongre,[1] Franck Ramus,[2] Nadège Villiermet,[2] Denis Schwartz,[3] and Anne-Lise Giraud[1,*]
[1]Inserm U960 - Ecole Normale Supérieure, 75005 Paris, France
[2]LSCP UMR 8554, CNRS, EHESS, Ecole Normale Supérieure, 75005 Paris, France
[3]CRICM, CNRS UMR 7225, Inserm UMR-S 975, 75013 Paris, France
*Correspondence: anne-lise.giraud@ens.fr
DOI 10.1016/j.neuron.2011.11.002

SUMMARY

It has recently been conjectured that dyslexia arises

deficit. One issue is whether phonological representa
themselves are degraded, or whether the ability to re
them from or store them into working and/or long-term me

Neuron 72, 1080-1090. December 2011

Scientific Learning®

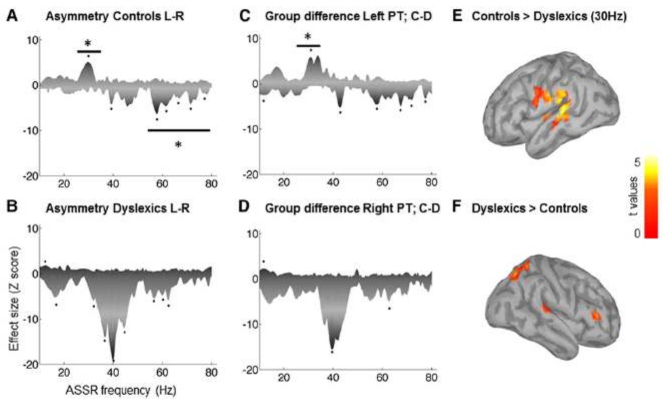


Figure 3. ASSRs Obtained in Response to the 5.4 s Noise Modulated in Amplitude between 10 and 80 Hz in the Planum Temporale

(A) ASSRs (left minus right) in controls show a left dominance in the 25–35 (sound)/25–35 (response) Hz range and a right dominance to AM frequencies above 55 Hz.

(B) Left dominance around 30 Hz is absent in dyslexics.

(C) In the left PT, controls show significantly stronger 30 Hz entrainment than dyslexics, and dyslexics display significantly stronger responses above 40 Hz.

(D) In the right PT, dyslexics display stronger responses at 40 and 60 Hz. Lines delimit significant clusters ($p < 0.05$). Points indicate significant local values (two-tailed t test, $p < 0.05$ uncorrected).

(E and F) Surface projection of the group difference at 30 Hz (representation of t values, one tailed, $p < 0.05$ minimum cluster size = 18).

See also Figure S3.

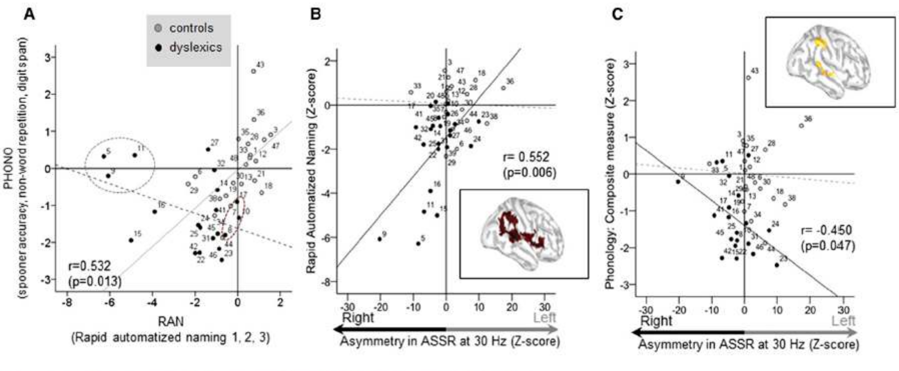


Figure 5. Individual Scores in Phonological Tasks and ASSR Asymmetry at 30 Hz

(A) Subjects distribution in each group along the two behavioral dimensions extracted from the test battery (PHONO and RAN, see Table S1). The gray circle indicates individuals with no phonological deficit but strong RAN impairment. The dark red circle indicates individual with no RAN deficit but strong phonological impairment.

(B and C) Correlations between the asymmetry in cortical entrainment at 30 Hz (positive and negative values indicate left and right dominance, respectively) in the planum temporale and behavioral dyslexia markers (Z-scores) obtained in both population samples. Positive correlation between ASSR asymmetry and RAN in dyslexics (A). This measure admittedly reflects phonological output as the input is nonverbal. There is no correlation in controls. Negative correlation between ASSR asymmetry and the average Z-score of PHONO (spoonerism, nonword repetition and digit span) is significant in dyslexics (B). PHONO spans the phonological input deficit. Surface renderings in (B) and (C) show the correlation between the behavioral measures and ASSR at 30 Hz in the right hemisphere of dyslexics. Colored areas represent p values < 0.05, dark red and yellow for positive and negative correlations, respectively.

See also Figure S4.

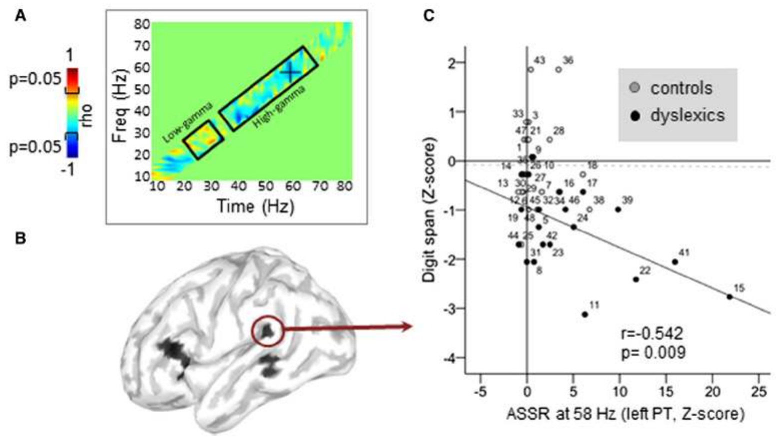


Figure 6. Oversampling and Working Memory Deficit in Dyslexics

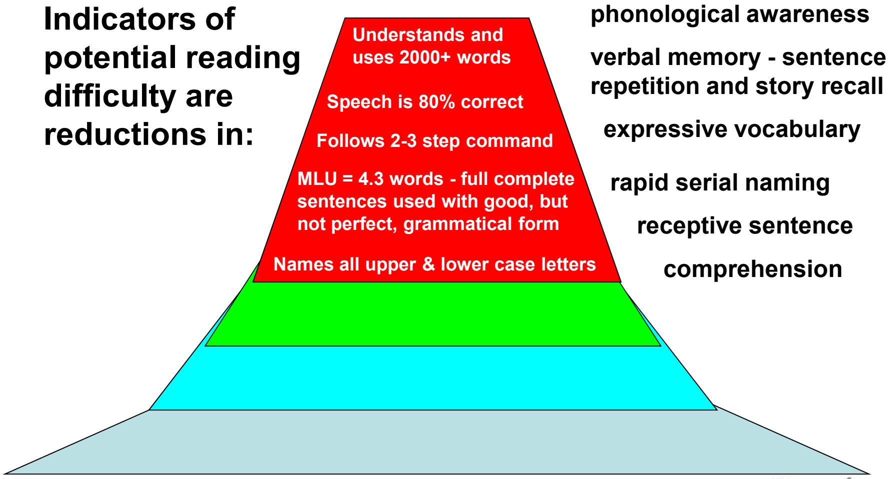
(A) Correlation between ASSR magnitude over the whole 10–80 Hz frequency range in dyslexic's left auditory cortices and behavioral scores for the digit span task. The black cross indicates where the difference between groups (ASSR magnitude above 50 Hz) is maximally significant.

(B) Cortical surface rendering of the left ASSR group difference (dyslexics > controls) at 58 Hz (black cross on A). The colored area represents p values <0.025 (one-tailed).

(C) Correlation between ASSR magnitude at 58 Hz in dyslexics' left auditory cortex and the behavioral Z-score for digit span (this measure reflects short-term memory) is significant in dyslexics but not in controls in each of the three colored areas.

Kindergarten

Indicators of potential reading difficulty are reductions in:



phonological awareness

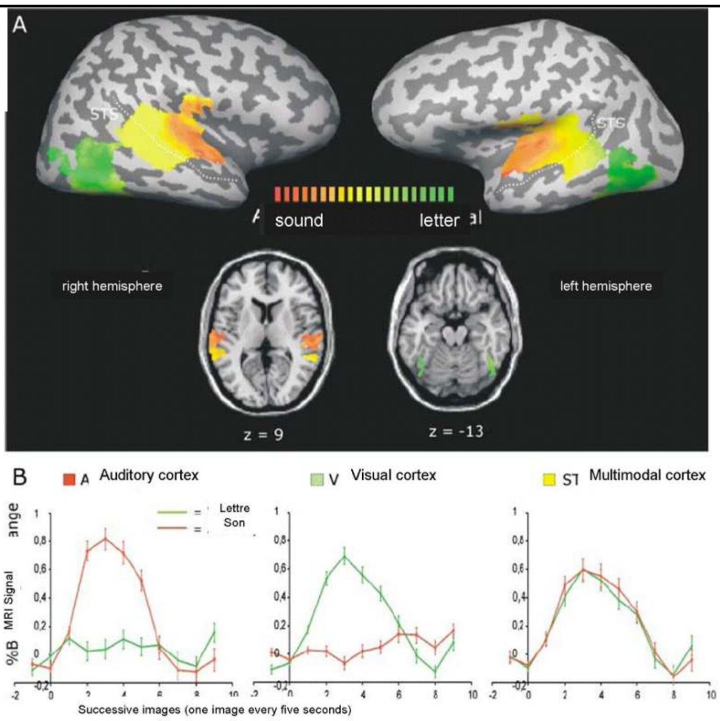
verbal memory - sentence repetition and story recall

expressive vocabulary

rapid serial naming

receptive sentence comprehension

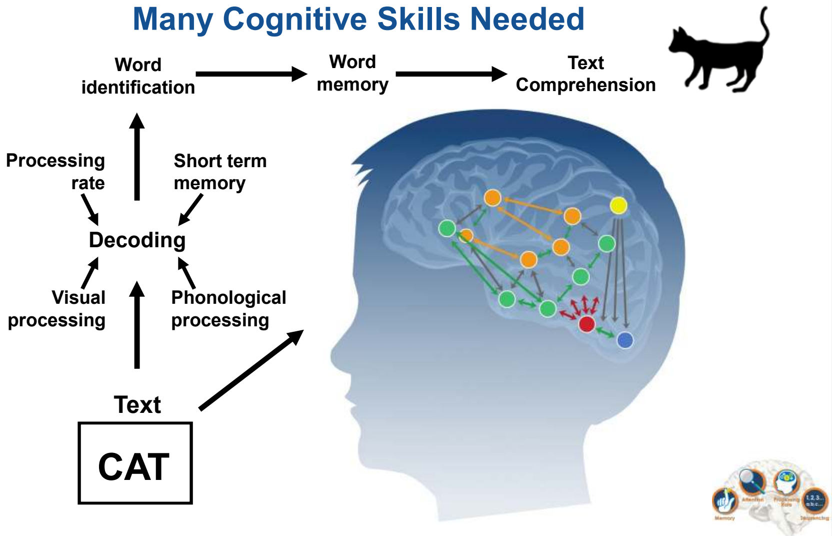
Dyslexia



A
STS
STS
sound
letter
right hemisphere
left hemisphere
z = 9
z = -13
B
A Auditory cortex
V Visual cortex
ST Multimodal cortex
Lettre
Son
%B MRI Signal
Successive images (one image every five seconds)

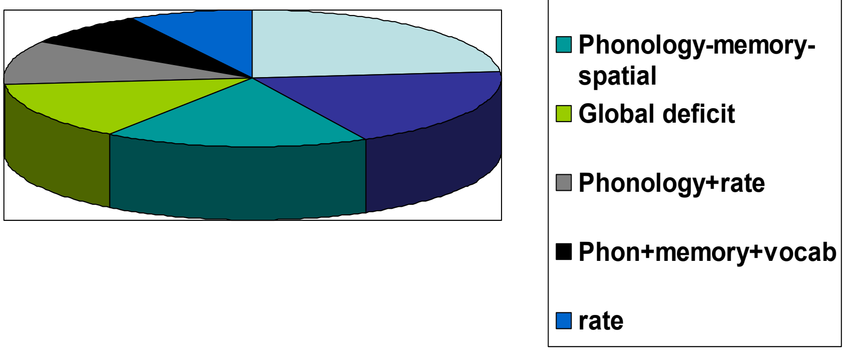
Reading: Mastering an Invented System

Many Cognitive Skills Needed



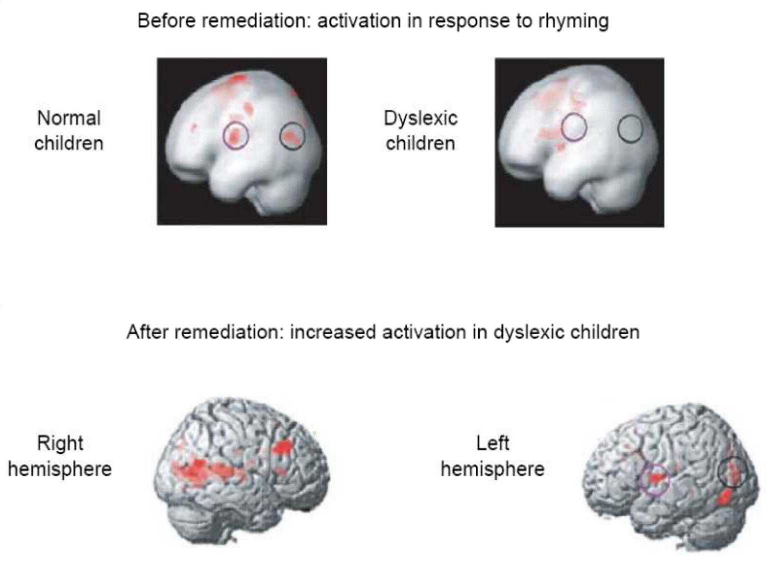
Scientific Learning

Subtypes of Poor Readers

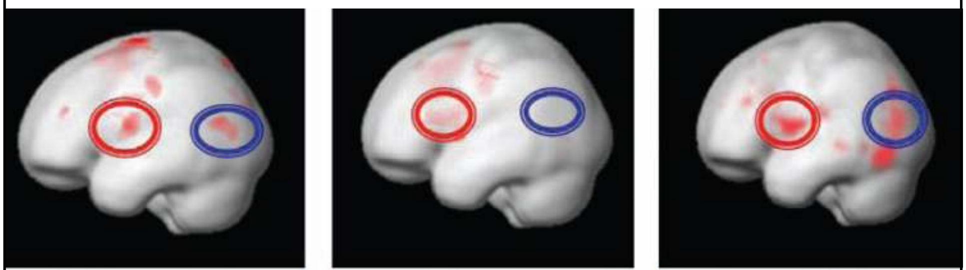


Adapted from Morris, R.D., Stuebing, K.K., Fletcher, J.M., Shaywitz, S.E., Lyon, G.R., Shankweiler, D.P., Katz, L., Francis, D.J., Shaywitz, B.A. (1998). Subtypes of reading disability: variability around a phonological core. Journal of Educational Psychology, 90 (3): 347-373.

Scientific Learning



TRENDS in Neurosciences



Typically reading children | **Children with dyslexia before remediation** | **Children with dyslexia after remediation**

Gabrieli, 2009

Factors in Reading Disorders (Lehongre, et al., *Neuron, Dec.* 2011*)*

- Left auditory cortex of dyslexic people may be less responsive to modulations at very specific frequencies that are optimal for phonemic analysis (30 Hz), while responding normally or even supranormally to higher frequencies
- detriment of verbal short-term memory abilities (Ahissar, 2007)
- Different patterns of cortical reorganization based either on the left or on the right hemisphere may lead to different cognitive profiles in dyslexia.

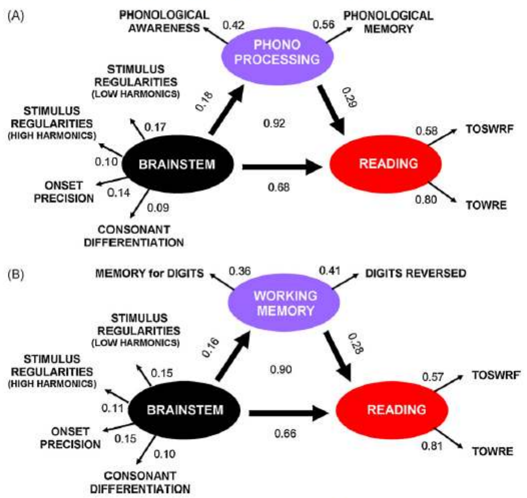


Fig. 4. Relationships between brainstem encoding of speech and reading remain robust with the inclusion of phonological processing and working memory. (A) Phonological processing skills contributed to the prediction of variance in reading, but the relationship between brainstem and reading remained significant and robust (Overall fit: $\chi^2 = 15.10$, $\chi^2/df = 0.89$, $p = 0.59$, RMSEA < 0.01). Phonological processing is abbreviated as Phono Processing due to space constraints. (B) Working memory skills also contributed to the prediction of variance in reading, but the relationship between brainstem and reading remained significant and robust (Overall fit: $\chi^2 = 12.21$, $\chi^2/df = 0.72$, $p = 0.79$, RMSEA < 0.01). All relationships between observed and construct factors were significant in both models, and R^2 values are indicated. *Note*: a model including both cognitive factors was attempted, but failed to be fitted. SEM methods fail when the number of elements of the model meets or exceeds the number of participants in the data set because each element is uniquely defined or under-defined [53].

What Dyslexia is not

- **Learning Disabilities, Dyslexia, and Vision** *Pediatrics* 2009;124;837-844; originally published online Jul 27, 2009;
  - Orthoptists; Pediatric Ophthalmology and Strabismus and American Association of Certifiedwith Disabilities, American Academy of Ophthalmology, American Association forAmerican Academy of Pediatrics, Section on Ophthalmology, Council on Children
- Scientific evidence does not support the efficacy of eye exercises, behavioral vision therapy, or special tinted filters or lenses for improving the long-term educational performance in these complex pediatric neurocognitive conditions
- Diagnostic and treatment approaches that lack scientific evidence of efficacy, including eye exercises, behavioral vision therapy, or special tinted filters or lenses, are not endorsed and should not be recommended.

Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset

Nora Maria Raschle[a,b], Jennifer Zuk[a], and Nadine Gaab[a,b,c,1]

[a]Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Department of Medicine, Children's Hospital Boston, and [b]Harvard Medical School, Boston, MA 02115; and [c]Harvard Graduate School of Education, Cambridge, MA 02138

Edited by Michael Merzenich, W. M. Keck Center for Integrative Neuroscience, University of California, San Francisco, CA, and approved December 8, 2011 (received for review May 17, 2011)

Raschle et al., PNAS Feb. 7, 2012

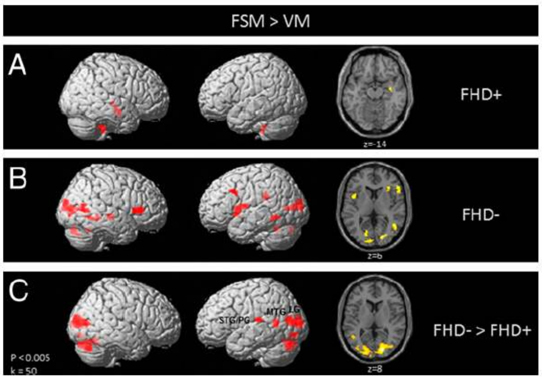
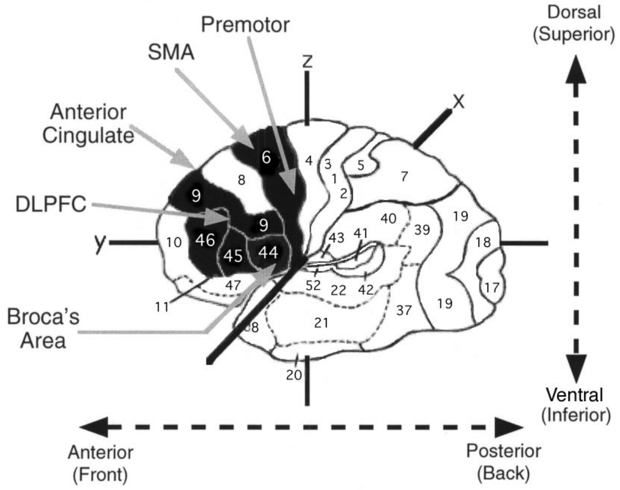


Fig. 1. Statistical parametric maps showing brain activation during phonological processing (FSM > VM) for children with (*A*) and without (*B*) a familial risk for DD, as well as group differences between children with compared to without ($FHD^- > FHD^+$) a familial risk for DD (*C*). FHD^- show significantly greater activation compared to FHD^+ children in bilateral occipitotemporal and left temporoparietal brain regions, as well as left and right cerebellar regions.

Executive Functions

Dorsolateral Pre-frontal lobe

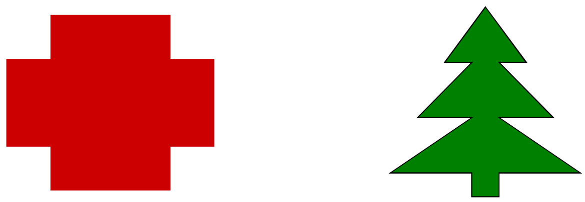


Smith E &Jonides J, *Science* (2009)

Task Switching

- Card sorting
- Go/no-go (Simon says)
  - Can increase complexity to increase task switching
- http://www.nytimes.com/interactive/2010/06/07/technology/20100607-task-switching-demo.html

Card sorting



- Red plus
- Green tree

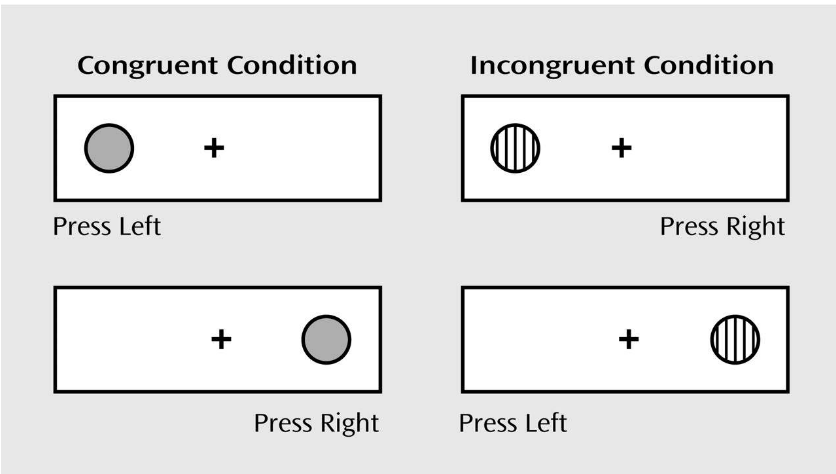
Activation Regulating Functions

- Damage to left or right medial frontal regions results in poor capacity to generate or maintain actions or mental processes
- Fluency tasks
- STROOP Test – problems maintaining a selected target
  - Sensitive to DLPFC and VMPFC lesions

Other Assessments used in research that can be applied for clinical use

- Dots incongruent vs. dots congruent
- Object or picture sorting where the sorting rule is switched

Dots mixed task



In the congruent condition, the correct response is to press the dot on the same side as the stimulus. In the incongruent condition, the response and stimulus are on opposite sides. In the mixed condition, equal numbers of congruent and incongruent trials are randomly intermixed.

Inhibition/distractibility

- Holding information in mind while inhibiting a prepotent response
  - Day-night
  - Tapping (When I tap once you tap twice)
  - Appearance-reality (clouds)
- http://www.nytimes.com/interactive/2010/06/07/technology/20100607-distraction-filtering-demo.html?th&emc=th

Scientific Learning®

How has technology changed?

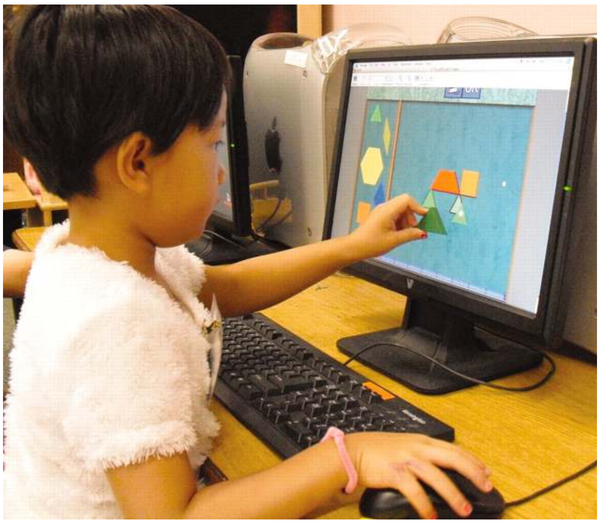
- Neuroscience derived exercises can build specific cognitive skills
  - Through game-like activities that upregulate neuromodulators of brain plasticity
  - Through targeted cognitive brain building exercises
    - Attention
    - Memory
    - Processing

Scientific Learning®

Earliest Technology

Learning

My How We Have CHANGED!



D H Clements, J Sarama Science 2011;333:968-970

Science AAAS

Published by AAAS

Learning

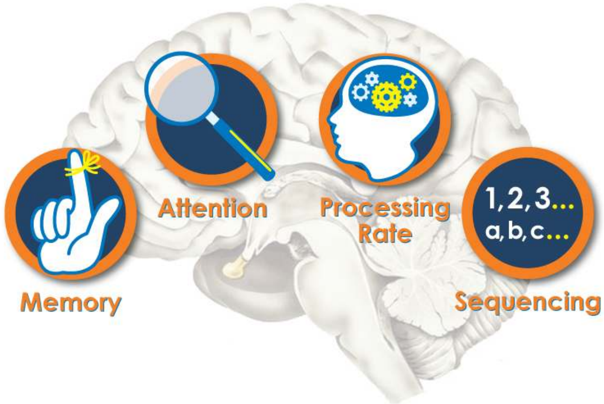
Brain Fitness: Processing Challenge

RED	GREEN	BLUE	YELLOW	PINK
ORANGE	BLUE	GREEN	BLUE	WHITE
GREEN	YELLOW	ORANGE	BLUE	WHITE
BROWN	RED	BLUE	YELLOW	GREEN
PINK	YELLOW	GREEN	BLUE	RED

Brain Fitness: Processing Challenge

RED	GREEN	BLUE	YELLOW	PINK
ORANGE	BLUE	GREEN	BLUE	WHITE
GREEN	YELLOW	ORANGE	BLUE	WHITE
BROWN	RED	BLUE	YELLOW	GREEN
PINK	YELLOW	GREEN	BLUE	RED

Brain Fitness



Memory

Improving fluid intelligence with training on working memory

Susanne M. Jaeggi*[†‡], Martin Buschkuehl*[†‡], John Jonides*, and Walter J. Perrig[†]

Proceedings of the National Academy of Sciences

May, 2008

Scientific Learning®

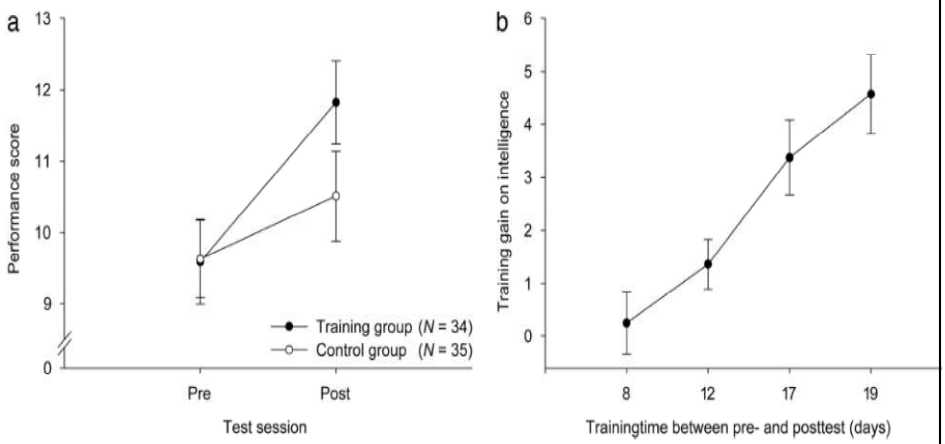
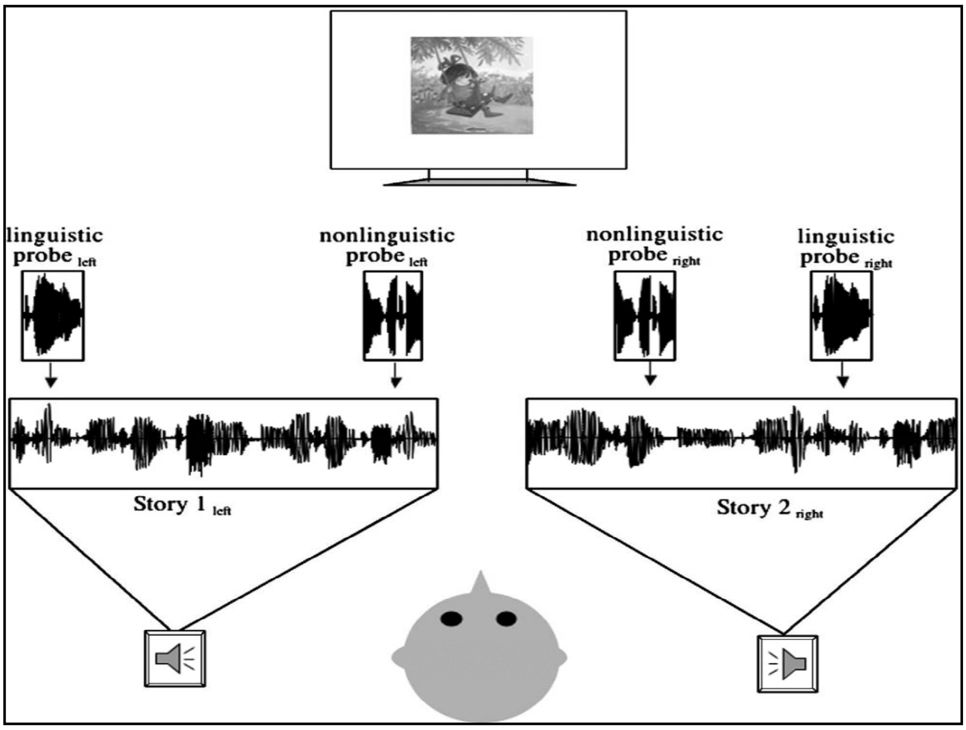


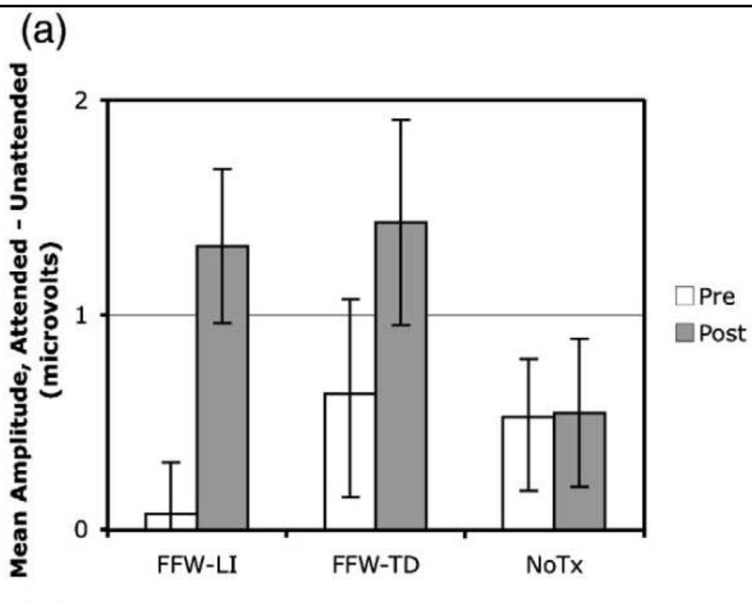
Fig. 3. Transfer effects. (a) Mean values and corresponding standard errors of the fluid intelligence test scores for the control and the trained groups, colla over training time. (b) The gain scores (posttest minus pretest scores) of the intelligence improvement plotted for training group as a function of training t Error bars represent standard errors.

Attention

Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children

- Courtney Stevens,, Jessica Fanning, Donna Coch,, Lisa Sandersa,, Helen Neville B R A I N R E S E A R C H 1 2 0 5 (2 0 0 8) 5 5 – 6 9





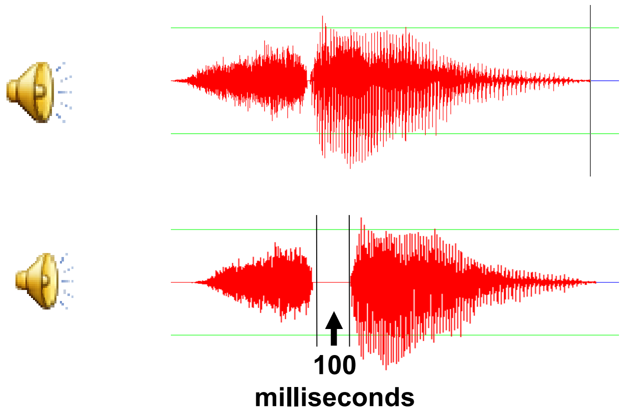
ERP attention effect for the FFW-LI, FFW-TD, and NoTx control groups, separately for pre- and post-testing

Processing

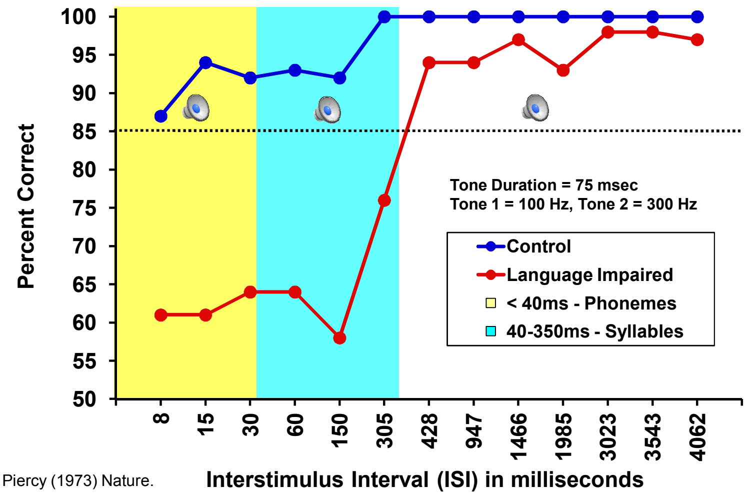
Processing Speech

- Students need to distinguish speech sounds correctly so they can learn the rules of language and associate sounds with letters
- Speech sounds can differ by as little as 10 milliseconds
- Computers can emphasize the differences in sounds to make them easier to distinguish

Small Changes in Timing
. . .Big Changes in Meaning



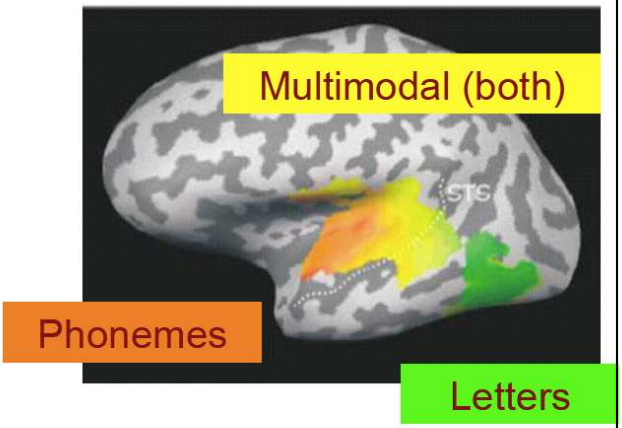
Children with language impairment can't sequence 2 tones at rapid presentation rates



Tallal & Piercy (1973) Nature.

Letter-Sound Connections

- Seeing letter activates letter area
- Hearing phoneme activates phoneme area
- Letter+Sound together
  - Matching-> Up Activity
  - Mismatching-> Down Activity



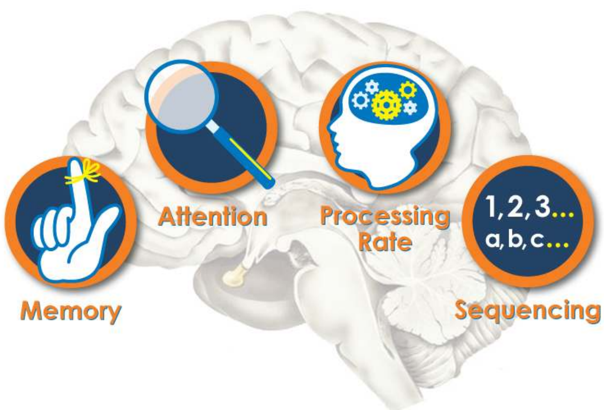
Brain Fitness

Brain-based learning interventions and best practice strategies

Martha S. Burns, Ph.D.

March, 2012

Brain Fitness



Scientific Learning

Neuroscience Based Principles of Brain Training

- Attention
- Memory
- Reinforcement and Novelty
- Intensity and Frequency
- Cross Training

Beyond early infancy, plasticity is modulated as a function of:

1. brightness
2. attention
3. judgment of error
4. punishment
5. Reward
6. et alia

See Kilgard & Merzenich, Science (1998)
Kilgard & Merzenich, Nature Neuroscience (1999)
Bao, Merzenich, et al, Nature (2001)

Scientific Learning®

Different dimensions of adult cortical plasticity are enabled by the behaviorally-context-dependent release of:

- **acetylcholine (focused attention/reward) (Kilgard, Bao)**
- **dopamine (reward, novelty) (Bao)**
- **norepinephrine (novelty) (Bollinger)**
- **serotonin (Bollinger)**
- **Adenosine 5'-triphospate (ATP) released by axons and stimulates myelination (Ishibashi)**
- **et alia**

In infants, exposure-based plasticity is relatively uniform.
In older children, learning-induced changes are complexly "nuanced" by differences in behavioral context that result in the differential release of 6 or 7 modulatory neurotransmitters.

Scientific Learning®

Attention

- little or no enduring changes are driven in the cerebral cortex if stimuli are delivered when an individual is not responding or attending
- underlying the human ability to focus and maintain attention to a task is the neurotransmitter acetylcholine which can be enhanced by the nature of tasks used (Kilgard and Merzenich, 1998)

Scientific Learning®

Memory

- changes in the cortex fade when a well-learned behavior does not have to be held in memory,
  - most likely because the cognitive relevance assigned to the task decreases;
- practice alone, without requirements for retention do not drive brain changes.

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Reinforcement and Novelty

- behavioral scientists had understood the power of timely reinforcement in learning since research on classical conditioning the 1950's;
- more recently neuroscientists began to understand why--specific reinforcement schedules and intermittent novelty drive neurotransmitters like dopamine and norepinephrine which are critical to creating permanent new neurological connections (Bao, et al., 2001)

Scientific Learning

Intensity and Frequency

- it takes thousands of repetitions of new stimuli to effect neurological changes; clinicians often refer to this as the "practice effect."

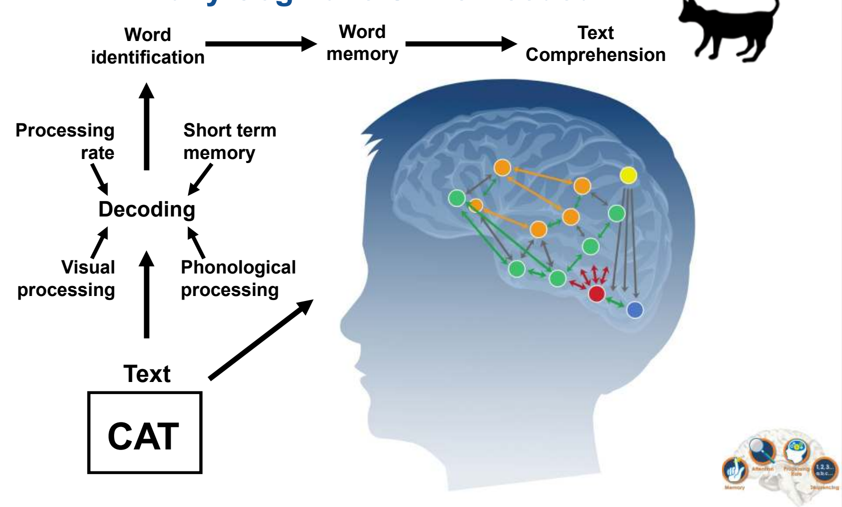
Scientific Learning

Adaptability

- the brain builds skill upon skill
  - by carefully grading stimuli to tasks that increasingly stress the brain to process faster or more efficiently, exercises can adapt to each individual's unique gains in skill

Reading: Mastering an Invented System

Many Cognitive Skills Needed



Cross Training

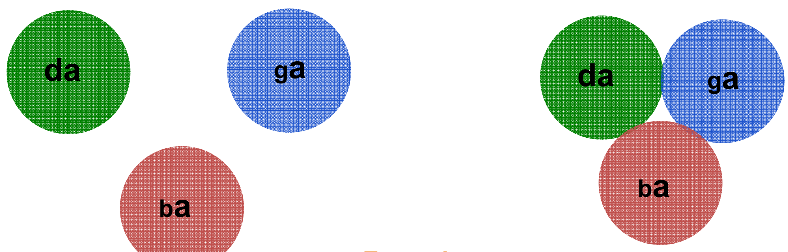
- The brain processes in networks of distributed neuronal clusters that develop simultaneously (Mesulam, 2000)
- Effective rehabilitation of language (a complex cognitive skill) would benefit from cross training all components of the language network.

Scientific Learning

Training Phoneme Examples

A) Early Emphasized and Stretched

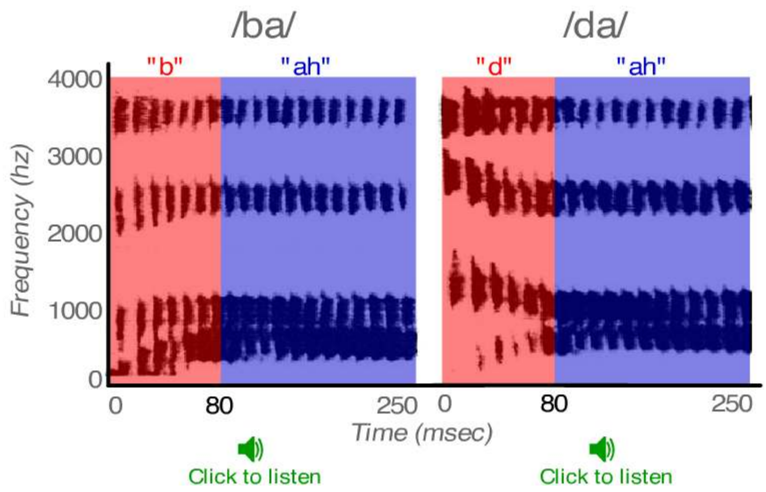
B) Late Natural Speech



Examples

Scientific Learning

Acoustically Modified Speech



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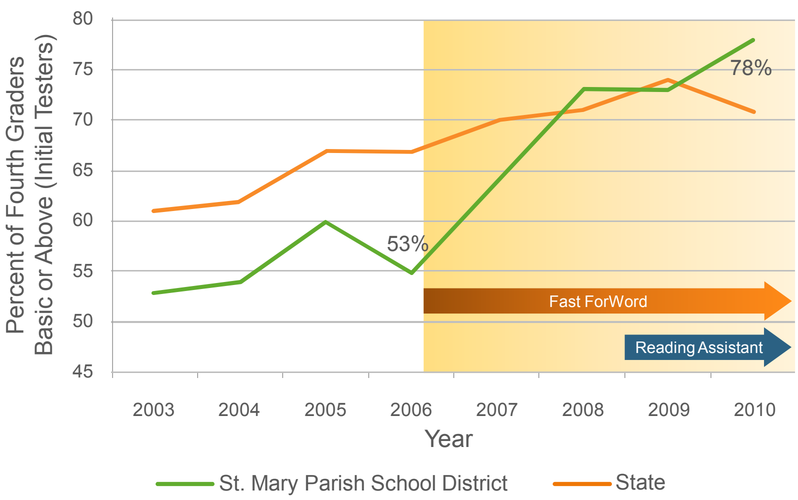
Accelerating Growth – District Wide



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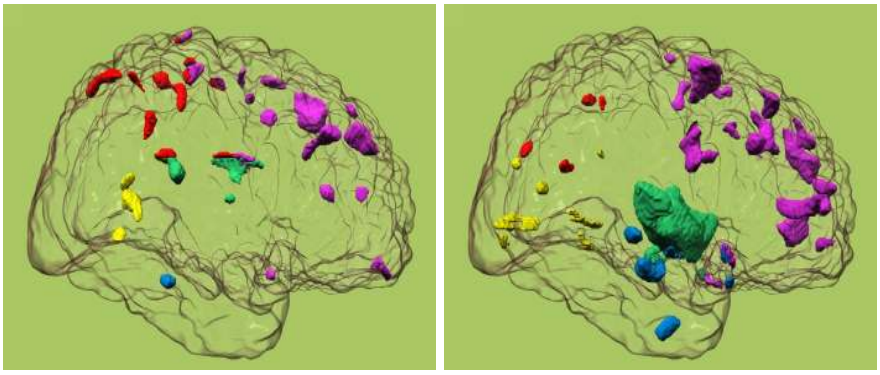
Changes in Brain Structure in Maturing Young People



Childhood to Adolescence
(Sowell et al, NeuroImage, 1999)

Adolescence to Adulthood
(Sowell et al, Nature Neuroscience, 1999)

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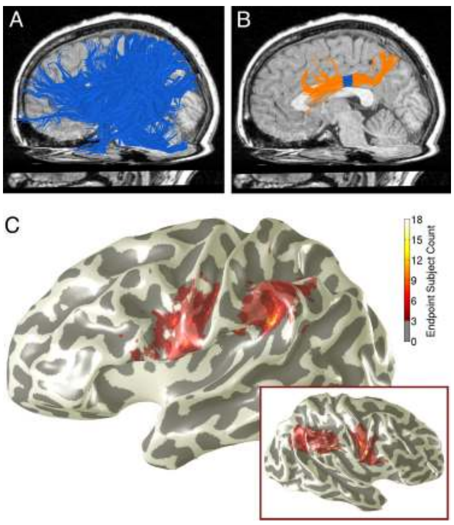
MATHEMATICS SKILLS - Identifying the aSLF.

Specific pathways in the left hemisphere communicate signals between regions that are active during mental arithmetic tasks.

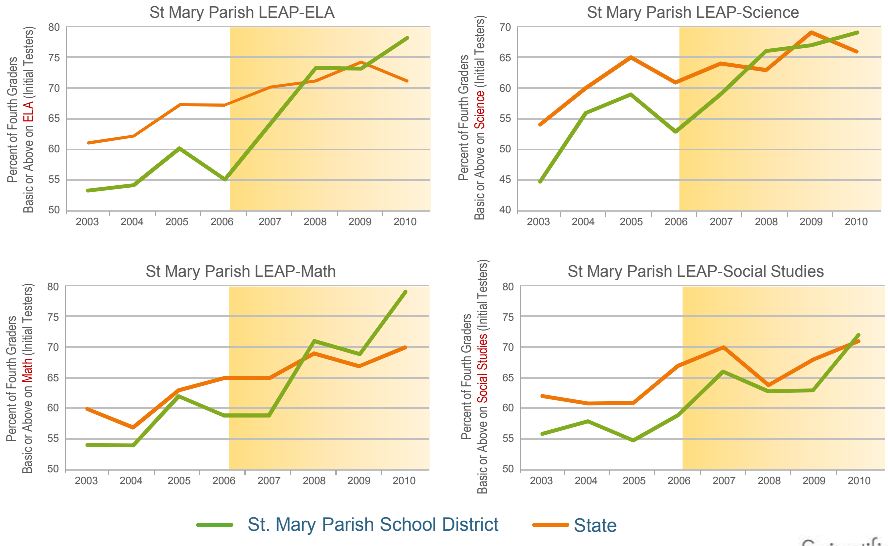


Tsang J M et al. PNAS 2009;106:22546-22551

These pathways connect the inferior parietal lobe/IPS with precentral and inferior frontal regions. Tsang et al., used diffusion-weighted data to estimate this white matter tract. Theyecall this tract the anterior superior longitudinal fasciculus (aSLF).

PNAS

…in Multiple Subjects



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Brain Fitness

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